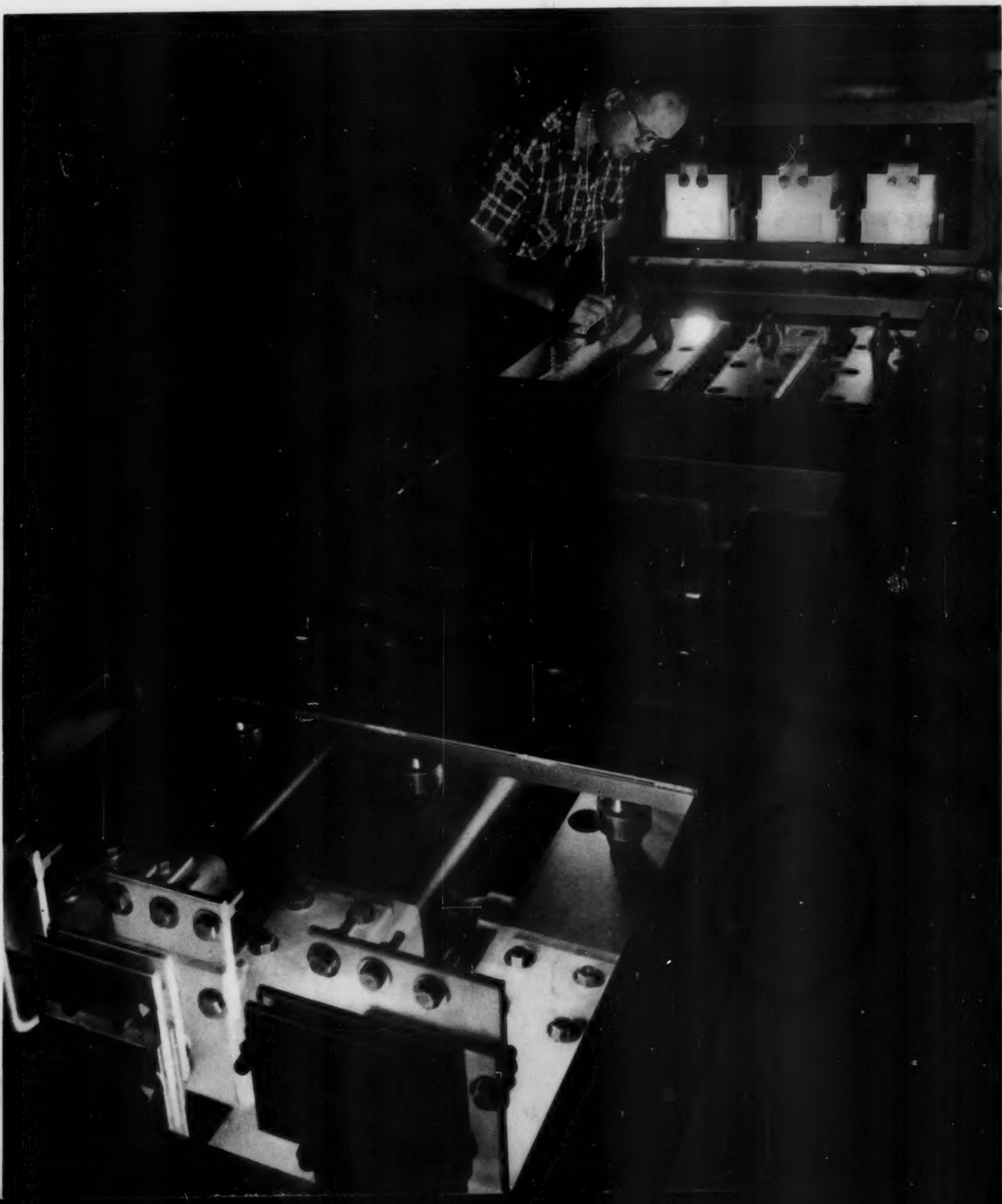
ALLIS-CHALMERS Electrical REVIEW

2ND QUARTER 1961



ALLIS-CHALMERS

Electrical REVIEW

THE COVER

PHASE AND GROUND SEPARATION for 4500-amp, 480-volt bus is maintained by new molded type glass polyester insulator posts. The high current metal-enclosed, ventilated, 7-inch square copper bus feed indoor station service equipment from outdoor 3750-kva transformer at Western utility.

Allis-Chalmers Staff Photo by Clarence Hansen

Allis-Chalmers

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Author's Preface

The Enrico Fermi Atomic Power Plant at Lagoona Beach, Monroe County, Michigan, is now undergoing extensive testing. The plant is part of a nation-wide private industry participation in the Atomic Energy Commission's Power Reactor Demonstration Program.

The reactor plant was designed by Atomic Power Development Associates, Inc., a nonprofit corporation of 42 member companies. The nuclear facilities of this plant are owned and will be operated by the Power Reactor Development Company, a nonprofit corporation supported by 25 member companies. The conventional steam turbine-generator facilities, which will utilize steam produced by the reactor, will be owned and operated by the Detroit Edison Company. Commonwealth Associates, Inc., is the architect-engineering firm for the nuclear portion of the plant, and United Engineers & Constructors, Inc. are construction engineers for both PRDC and Detroit Edison.

The plant site consists of 915 acres, about 30 miles southeast of Detroit, on the shore of Lake Erie. The plant area proper, approximately 15 acres, includes an 8 acre reactor site, and a turbine-electric plant occupying 7 acres. The Detroit Edison Company owns the entire property and has leased the reactor site to PRDC.

PLANT CAPACITY	**104,000 kilowatts**
REACTOR	
Power (heat)	**300,000 kilowatts**
Critical mass (U-235)	**444 kilograms**
Breeding ratio	**1.2**
U-235 consumed per year	**87 kilograms**
Plutonium produced per year	**106 kilograms**
Fuel alloy	**U-10% Mo**
Uranium enrichment	**25.6%**
Core diameter	**30.5 inches**
Core length	**30.5 inches**
Sodium velocity	**31.2 feet/second**
LIQUID METALS AND STEAM PLANT	
Net thermal efficiency	**31.3%**
Primary sodium temperatures	
Leaving reactor	**800 F**
Entering reactor	**550 F**
Sodium flow	**13,200,000 lb/hr**
Secondary sodium temperatures	
Entering steam generator	**750 F**
Leaving steam generator	**500 F**
Steam pressure	**575 psig**
Steam temperature	**742 F**

"The country which first develops a breeder reactor will have a great competitive advantage in atomic energy," Enrico Fermi, Los Alamos, 1945.

FAST BREEDER REACTOR PLANT on shore of Lake Erie will generate power for Detroit area while producing more fissionable fuel from non-fissionable materials than it consumes in the process.

KEY TO NUCLEAR FUEL CONSERVATION ...THE ENRICO FERMI PLANT

ALTON P. DONNELL
General Manager
Atomic Power Development
Associates, Inc.

Vital to U. S. nuclear power progress and leadership is completion of world's largest fast breeder reactor plant.

ENRICO FERMI PLANT ATOMIC FURNACE is a large fast-neutron breeder type reactor much needed for the nation's power reactor program. While all nuclear reactors depend on a self-propagating chain reaction of nuclear fission, in the most common nuclear reactors, the thermal type, the fission process is maintained by thermal low-energy (slow) neutrons, but in a fast breeder reactor the fission process is maintained by high energy (fast) neutrons. The fast reactor has many attractive characteristics and inherent advantages, the most significant of which are:

1. The fast reactor can produce a larger quantity of fissionable fuel from non-fissionable U-238 and thorium than it consumes in the process.

2. Because the fast reactor is inherently a breeder, a virtually complete utilization of the existing nuclear fuel resources is possible. And as a result, the raw material cost of the fuel should be very small and the fuel cycle cost itself should be low. This utilization of nuclear fuels is necessary to support a large-scale atomic power program.

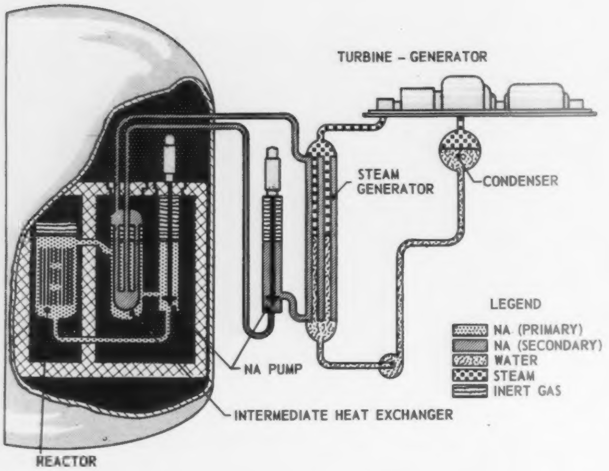
3. Once stocked with an initial fuel charge, a breeder reactor would not constitute a drain on either the strategic government-owned stockpile of fissionable material or on the facilities for the production of fissionable material. Consequently, the operation of a fast breeder reactor could be independent of government pricing policies.

4. Fast neutrons are not readily absorbed by structural materials, coolants, and fission products. Therefore, almost complete freedom in the choice of structural materials and coolants is afforded the reactor designer. The lifetime of fuel elements is limited not by the build-up of fission-product poisons but only by irradiation damage considerations.

5. Because sodium can be used as the coolant in a fast reactor, high temperatures and high thermal efficiencies are attainable with low operating pressures.

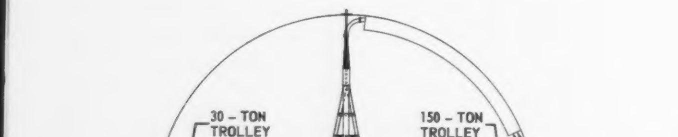
6. Operation at high neutron energy provides a small core with high power density, freedom from large hot-spot effects that exist in some thermal reactors, and small reactivity requirements for control.

Figure 1 shows schematically the plant operating principle. The reactor is designed so that the 300 megawatts of heat generated in the combined reactor core and blanket will be conveyed by liquid sodium to the inter-



HIGH THERMAL EFFICIENCY and high temperatures are possible with sodium, Na, for reactor coolant. Heat from primary sodium coolant, is transferred to the secondary sodium loops in intermediate heat exchangers. Non-radioactive steam for turbine-generator is produced by secondary sodium in steam generators. **(FIGURE 1)**

CAPSULE-LIKE CONTAINMENT BUILDING houses the reactor, primary sodium loops and intermediate heat exchangers. Reactor portion is below grade and shielded from other buildings. **(FIGURE 2)**



mediate heat exchangers. The primary sodium pump will return the liquid sodium to the reactor. There are three such sodium loops attached to the reactor. Heat is taken from the intermediate heat exchanger by secondary sodium and conveyed to the once-through type of steam-generator. Liquid sodium is returned to the intermediate heat exchanger by the secondary sodium pumps. There are three such steam-generators and secondary sodium loops. Steam at a pressure of 575 psig and 742 F from the steam-generator will produce electric power in the 1800-rpm condensing turbine-generator. Ultimately, it is expected that the reactor will produce 430 megawatts of heat and the turbine-generator 150 megawatts of electric power.

Extensive care taken with sodium circuits

Extensive steps have been taken to assure that sodium will not be lost from the system. Syphon breaks, secondary containment of the primary sodium system and enclosure of the reactor vessel in a leak-tight primary shield tank, so sized and constructed that adequate cooling can be maintained even if the reactor vessel fails, guard against

STEAM GENERATORS operating on sodium from secondary pumps provide steam at 575 psig and 742 F for the turbine. The turbine and its condenser are free of harmful radioactive contamination. **(FIGURE 3)**

1. **STEAM GENERATOR HOUSE.** 2. **GASTIGHT BUILDING.** 3. **TRANSFER CASK CAR.** 4. **PRIMARY SODIUM OVERFLOW TANK.** 5. **REACTOR.** 6. **PRIMARY SODIUM PUMP.** 7. **INTERMEDIATE HEAT EXCHANGER.** 8. **SECONDARY SODIUM PUMP.** 9. **STEAM GENERATOR** 10. **SECONDARY SODIUM DUMP TANK.** 11. **CONTROL ROOM.** 12. **TURBINE-GENERATOR**

CENTRALIZED CONTROL governs the reactor plant under normal conditions from shutdown to maximum rated power output. It includes equipment for manual start-up, manual and automatic control throughout the power range, automatic power level setback and operational monitoring. An equipment handling section provides remote control of plant components within the reactor building. Closed circuit television gives the operator visual information. **(FIGURE 4)**

loss of the sodium. Failure of the primary system resulting from thermal shock has been guarded against by extensive use of thermal baffles and by-pass flow.

Figures 2 and 3 show relative positions of the equipment in the plant. The containment building, housing the reactor vessel, primary shield tank, primary sodium piping, intermediate heat exchangers (IHX), and primary sodium pump are shown in Figure 2. The capsule-like containment building is 72 ft in diameter and 120 ft high.

The steam generation equipment and electric generation facilities are housed in connecting buildings that are separated from the reactor containment buildings. The control room is shown in Figure 4. The office building, sodium clean-up and storage building, gas clean-up building, fuel and repair building, health physics building, water tower, and miscellaneous facilities are not shown in the drawings.

A perspective view of the reactor and primary shield tank is given in Figure 5. The reactor vessel, which weighed 92 tons when initially placed in position, is fabricated from type 304 stainless steel with wall thickness varying from 1⅛ in. to 2 in. It is approximately 36 ft from bottom to top and about 14 ft in diameter at its widest part. The total weight of the reactor vessel with its internal shielding and rotating plug is approximately 350 tons. The entire reactor vessel is contained within the primary shield tank. This tank is an all-welded, carbon steel vessel which is basically a flat bottomed, right circular cylinder, 24 ft in maximum diameter, capped by a hemispherical "machinery" dome. The primary purpose of the tank is to serve as a container for a neutron absorber consisting of borated graphite and plain graphite blocks stacked in a dense lattice around the upper and lower portions of the reactor vessel.

An important second function of the tank is to act as a standpipe for secondary containment of molten sodium in the event of a leak in the reactor vessel or associated piping. Fuel and blanket elements are housed within the lower reactor vessel and are cooled by sodium that flows from the bottom of the lower reactor, through the elements, and up into the upper reactor vessel, which serves as a mixing pool. The upper reactor vessel will be operated at approximately atmospheric pressure with an inert gas atmosphere above the sodium.

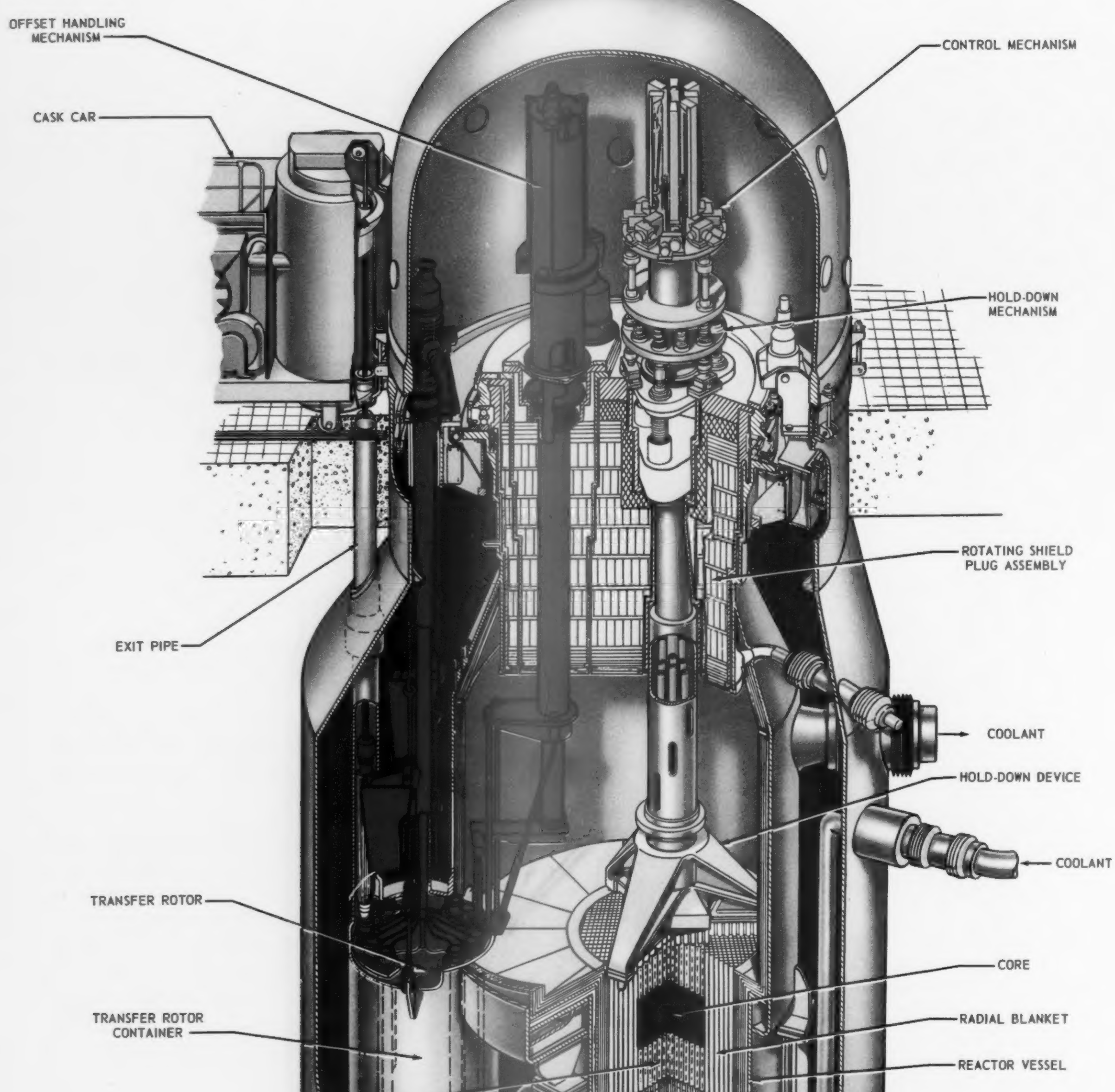
Hold-down device and rotating plug required careful design

The upper reactor vessel houses the core hold-down device and the offset fuel handling mechanism. The hold-down device, consisting of the hold-down plate, alignment spider, hold-down column and drive mechanism, will maintain radial alignment of the upper ends of the core subassemblies, hold the subassemblies down against uplift resulting from sodium flowing up through the subassemblies, and provide guidance for the control rod drives.

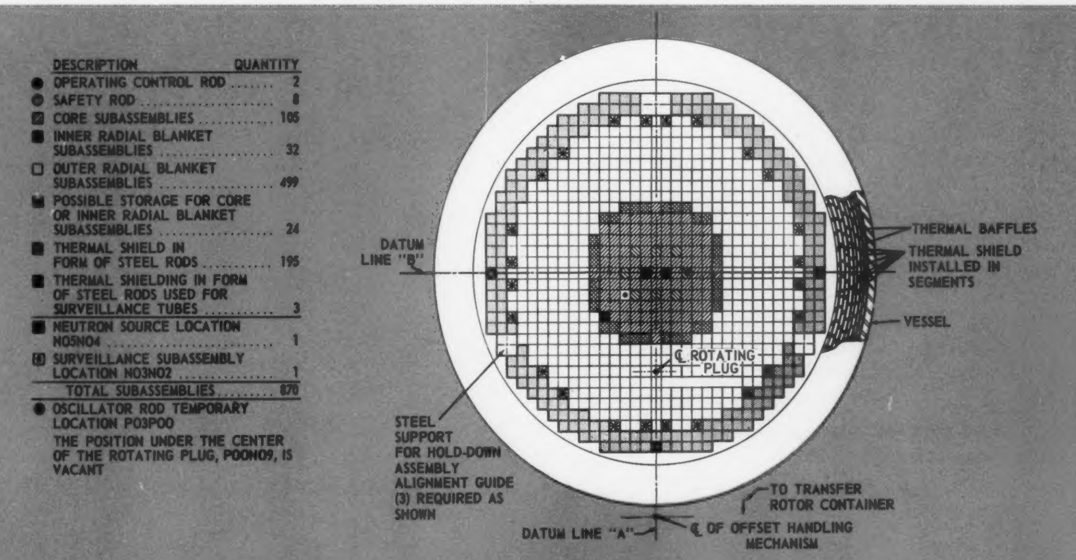
The rotating plug is located at the top of the reactor vessel, with both the hold-down device and the offset handling mechanism mounted eccentrically on it. When the plug is rotated the hold-down device is swung away from the core as the handling mechanism is swung over the core.

The vessel was fabricated with the centerlines of the plug container and lower reactor vessel concentric within 40 mils to assure alignment of tne rotating plug with the core, the hold-down device during operation and the offset handling mechanism during refueling.

Components of the primary fuel handling system, which are used to remove spent fuel and blanket elements from the reactor and to replace them with fresh elements, are located above and immediately adjacent to the reactor. The equipment consists of the offset handling mechanism, the rotating shield plug and drive, and the transfer rotor, assembled as shown in Figure 5. Motions of the plug and offset handling mechanism enable withdrawal of elements from any position in the reactor lattice and placement into the transfer rotor. The transfer rotor provides storage



CORE AND BLANKET SUBASSEMBLIES are loaded and unloaded by offset handling mechanism mounted in rotating shield plug. The hold down mechanism holds core subassemblies against the forces caused by coolant flow. Spent fuels are placed in transfer rotor container from which they can be lifted into the cask car. **(FIGURE 5)**



REACTOR CROSS SECTION gives arrangement of core and blanket subassemblies. **(FIGURE 6)**

space under sodium during the period immediately after removal from the reactor when heat release is at its highest. Spent fuel and blanket elements will remain in the rotor between fuel transfer periods and will be transferred from the sodium to a cask car while charging the reactor with fresh fuel. This arrangement minimized the reactor shutdown time required to transfer fuel. Provision was also made for storage of spent fuel elements in the outer edge of the radial blanket, should it be desirable to unload more than 11-element capacity of the transfer rotor at one time.

The reactor is an assembly of 870 removable and, to a certain extent, interchangeable units, all assembled on a square lattice spacing of 2.693 in., as shown in Figure 6. A pair of properly pierced lower support plates that are attached to the reactor vessel provide the basic definition of this lattice and support the fuel and blanket regions. The core and blanket, which are shown in Figure 7, consist of an assembly of square core and blanket elements arranged to approximate a right circular cylinder about 80 in. in diameter and 70 in. high over-all. The core, containing the enriched fuel alloy, approximates a right circular cylinder 30.5 in. in diameter and 30.5 in. high; it is completely surrounded by the breeder blanket.

The reactor core, for operation at about 200 Mwt, is made up of the central portions of 115 elements, 105 of which contain fuel, the remaining 10 being control elements. Fuel is subdivided into a large number of partially enriched uranium alloy pins. The end portions of these 105 subassemblies (the axial blanket), and all the 555 radial blanket subassemblies, consist of uranium alloy that has been depleted in U-235 and fabricated into cylindrical rods. Plutonium is produced both in the core and in the blanket.

Three regions in each fuel element

Each fuel element is composed of three basic regions — a lower axial blanket, the fuel-bearing core region, and an upper axial blanket — that are mechanically incorporated into a single structure to facilitate handling. The fuel region of each core subassembly is made up of 140 round uranium-10 w/o molybdenum alloy pins containing uranium enriched to 25.6 percent in U-235. Each pin is clad with 5 mils of reactor grade zirconium that is metallurgically bonded to the periphery of the fuel alloy and closed at the top and bottom with zirconium end-caps. The over-all length of the pins is $32\frac{1}{16}$ in., and the outside diameter is 0.158 in. The pins are maintained on a square pitch of 0.200 in. in a cartridge made of stainless steel plates and "egg-crate" supports. This cartridge restricts the fuel pins from bowing or warping to prevent undesirable reactivity fluctuations. The lower end of each pin is fastened to the cartridge by anchor bars that are threaded through the slotted bottom end-caps. The upper ends are free to accommodate changes in length resulting from temperature changes and irradiation effects.

The upper and lower axial blanket regions each contain 16 — 0.415-in. diameter U-2.75 w/o Mo alloy rods containing uranium depleted to 0.35 percent in U-235; they are spaced around the periphery of the element. The rods are enclosed in 10-mil stainless steel tubes having an outside diameter of 0.443 in. The radial clearance between the uranium alloy and the tube is filled with sodium to provide a bond with low thermal resistance. Allowance for increase in length of the alloy because of thermal expansion and irradiation effects is provided inside the seal tube by the sodium annulus and a gas space above the rod.

Fuel and blanket elements will be programmed to

remain in the reactor until the maximum allowable burn-up is attained. Spent fuel and blanket elements will be removed from the reactor and taken from the reactor building to the fuel and repair building in a heavily shielded cask which is part of an electrically driven, self-propelled fuel transfer cask car shown in Figure 8. Cautious cooling is required during these operations because of the internal heat generation.

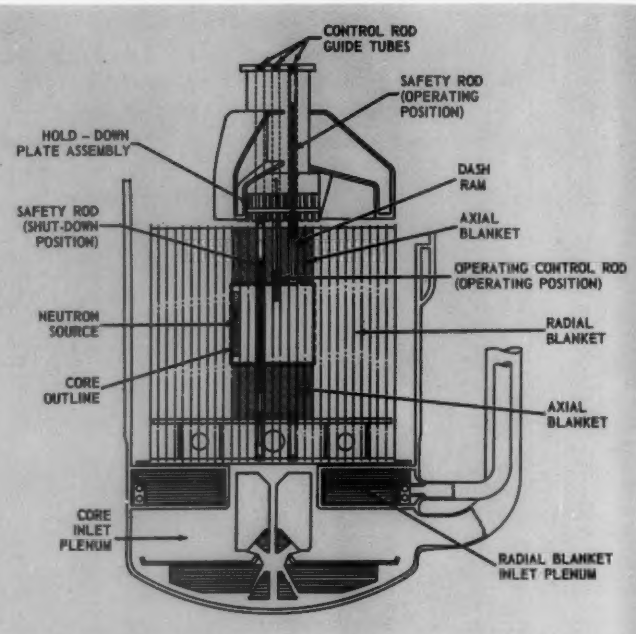
In the fuel and repair building, spent elements will be stripped of sodium, with superheated steam mixed with inert gas, and rinsed with water. The elements are subsequently transferred to a decay storage pool. After a 3 to 6 month decay period, the fuel elements are cut up to remove the fuel and blanket sections for shipment to reprocessing plants, while the blanket elements are shipped intact along with the blanket sections from fuel elements. Strict accountability is maintained for all fuel and blanket elements.

There are 10 poison control elements located in the core section of the reactor; eight are safety rods and two are operating control rods. The neutron absorbing material used is boron carbide containing boron enriched in boron-10, which has a significant absorption cross section for fast neutrons resulting from the B^{10} (n,a) Li^7 reaction. The 8 safety rods are spaced nearly uniformly in a ring approximately 7 in. from the core vertical centerline; the two operating control rods are 2.5 in. on either side of the core vertical centerline. During reactor operation the safety rods are held by a latch above the top of the upper axial blanket. The operating and shut-down positions of the safety and operating control rods are shown in Figure 7.

For the protection of personnel and equipment the reactor is surrounded by a complex of shielding material composed principally of concrete, steel, and graphite. The primary shield consists of a 12-in. stainless steel thermal shield inside the reactor vessel and a 30-in. partially borated graphite shield between the reactor vessel and the primary shield tank. The thermal shield, positioned against the inner wall of the reactor vessel, protects the vessel from radiation damage from fast neutrons and also absorbs gamma rays, thus reducing heat generation within the vessel walls and the borated graphite.

Sodium flows by gravity in primary system

The primary system sodium flows by gravity from the free surface pool of the upper reactor vessel to the shell side of the intermediate heat exchanger and then to the pump tank. The space above the sodium in each piece of equipment is filled with argon gas, and these gas spaces are interconnected by means of gas equalizing lines. Sodium is pumped from the pump tank back to the reactor, delivering approximately 90 percent of the flow to the plenum serving the reactor core and approximately 10 percent to the plenum serving the radial blanket. The flow of coolant to the blanket plenum is adjusted by means of a partially-closing throttle valve. Flow meters are located on both the core and blanket return lines. The primary coolant system has been designed to insure that the reactor is adequately cooled during all conceivable emergency conditions. The primary system is made up of



SAFETY RODS are used to "scram" the reactor in the event of unusual operating conditions. They are also inserted after normal shutdown. Fuel elements are divided into a lower axial blanket region, a fuel-bearing core region and an upper axial blanket region. (FIGURE 7)

three identical coolant loops, each of which includes a 12,800-gpm primary sodium pump, throttle valve and intermediate heat exchanger. The installation of the primary system is virtually complete, and testing is well along.

The secondary coolant system is the intermediate link that transfers heat from the primary coolant system to the steam generator. It consists of three loops, corresponding to the three loops of the primary system, and includes the tube side of the intermediate heat exchanger, the shell side of the steam generator, and the secondary coolant pump. Figure 9 shows a steam generator.

Exhaustive test program underway

Atomic Power Development Associates, Inc. has had the responsibility for the development of the reactor and primary coolant system for the Enrico Fermi plant. In carrying forward this responsibility, APDA has procured and assembled the major components and has conducted exhaustive hydraulic and mechanical nonnuclear tests of the reactor and one coolant loop under plant operating conditions. The tests are demonstrating that major components in the reactor and primary system, including the reactor vessel and surrounding tank, rotating shield plug, fuel handling mechanism, control rod drives, sodium pumps, sodium purification equipment, instrumentation, and piping, operate satisfactorily. The series of tests was conducted first in air at ambient and elevated temperatures and then in sodium at elevated temperatures. At this time, the primary system has been filled with sodium, and the major pieces of equipment have operated satisfactorily —

a major milestone in the development of the Enrico Fermi plant and in carrying forward the development of the liquid metal cooled fast breeder reactor in general.

The testing program consists of three principal steps to check the performance of equipment in three different environments, with each successive test being more realistic than its predecessor and more difficult to accomplish.

Tests in the first step were performed in air at room temperature to demonstrate that all pieces worked together as a unit. Under these conditions, measurements and modifications could be made with ease. In the second step, the equipment was tested in air at temperatures up to approximately 500 F, the normal refueling temperature.

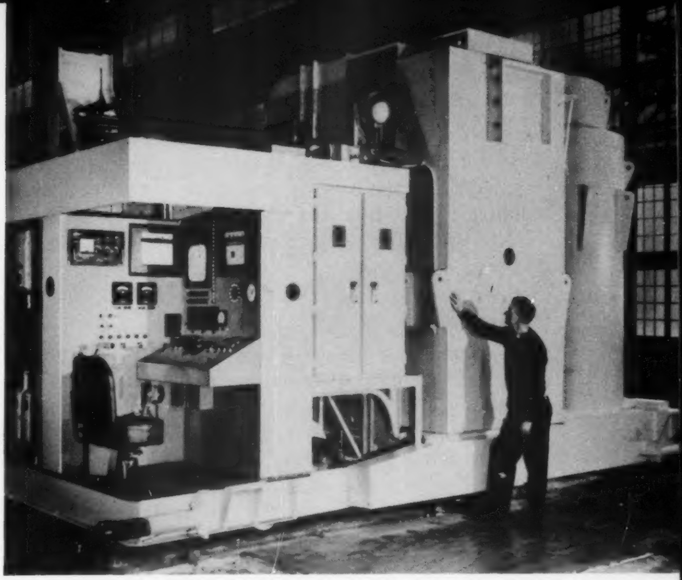
Tests in sodium simulate operating conditions

In the third test step, the entire primary system of the Enrico Fermi plant, which comprises the world's largest liquid metal cooled reactor system in operation, was filled under vacuum to its operating level with 345,000 lb of sodium during a 9 hr period. This sodium had previously been purified by circulating it between the cold trap and the storage tanks. The primary system was further purified by circulating the sodium through the cold trap with an overflow pump until the oxide content was reduced to less than 10 parts per million; purity checks during this and subsequent operations showed very little pickup of impurities from the system or from leaks, attesting to initial system cleanliness and leak-tightness. From a quartz window installed over the sodium surface, examination of the sodium surface showed it to be silvery bright, more like a large pool of mercury than a material which oxidizes readily.

The temperature, pressure, flow and sodium level measuring devices, and the auxiliary pumps operated satisfactorily in sodium at temperatures up to 500 F. Prototype control rod operation, activation of the fuel hold-down mechanism, and rotation of the reactor vessel plug have been demonstrated and tested with gratifying results. All three main sodium pumps, which are the world's largest pumps for sodium service, have been operated at minimum speed for one hour, and as of May 1, 1961 one of the pumps has been operated smoothly and quietly for over 1350 hours at various loadings up to a maximum of 13,100 gallons a minute.

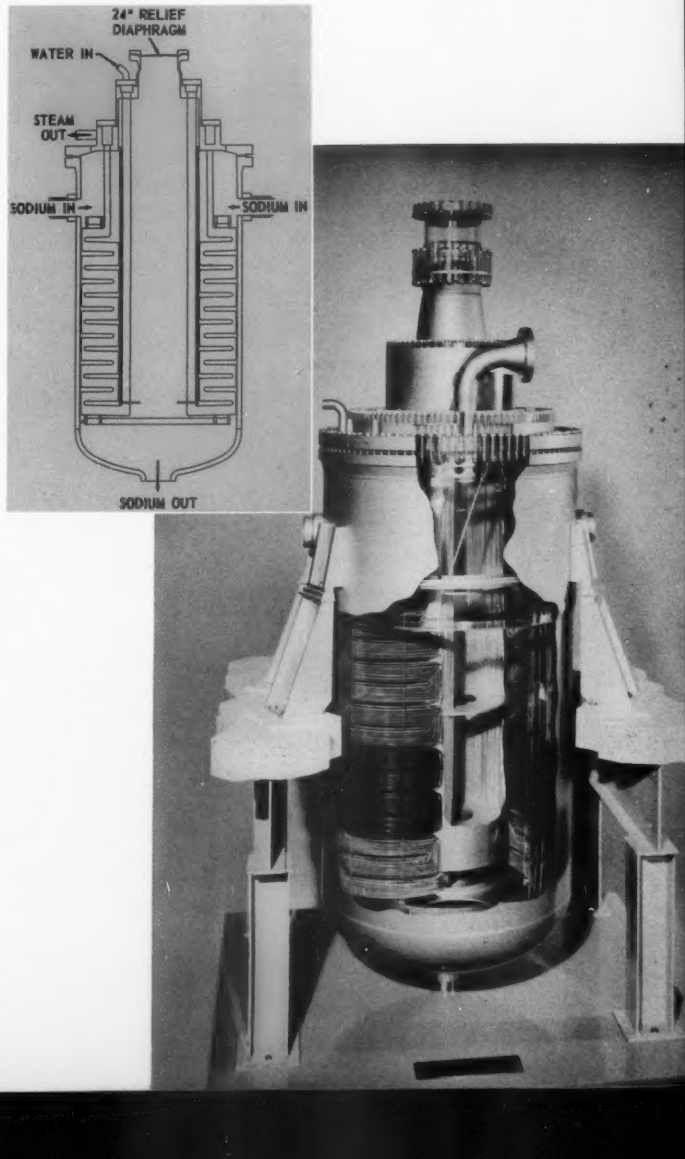
The experience with the sodium system has been excellent, and there is no evidence of corrosion, leaks, or deterioration. Purified argon gas at a pressure which is just above atmospheric pressure assures that oxygen will not get into the system even in the event of a seal failure.

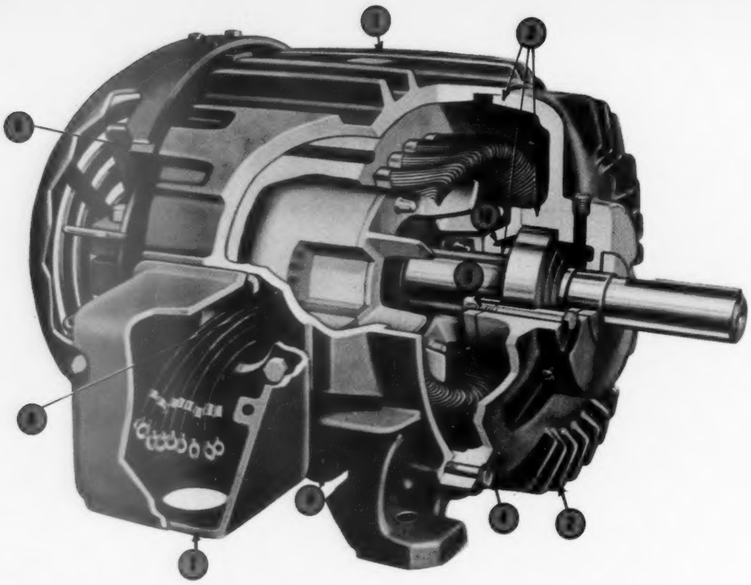
A big technological step forward is being made in the confirmation that operating equipment in a sodium environment presents no major difficulties. As long as oxygen is kept from the system, it appears that the system could work satisfactorily for an indefinite period. By showing that the alignment of equipment over long distances can be maintained at varying temperatures and with the successful operation of the components in sodium, the demonstration of the use of the large sodium systems for fast reactors appears to be well in hand. ◆



CASK CAR is equipped with a cable-actuated gripper and rotor plate to remove and transport several subassemblies. Car can be positioned over and sealed to the transfer rotor exit pipe. Finned pots containing spent subassemblies can be removed from reactor transfer rotor and fresh subassemblies introduced. **(FIGURE 8)**

STEAM GENERATORS are vertical, shell-and-tube, counterflow, once-through type units with water and steam in single-wall tubes and sodium on the shell side. Model shows tube arrangement. **(FIGURE 9)**





HOW MUCH MOTOR ENCLOSURE FOR HAZARDOUS AREAS?

D. N. HIGH
Motor and Generator Department
and
D. K. RUSSELL
Norwood Works
Allis-Chalmers Mfg. Co.

DETAILS MAKE THE DIFFERENCE between totally enclosed motor (above) and explosion proof motor (below). Points of difference are at: (1) yoke, (2) bearing housing, (3) fits, (4) bolts, (5) holes, (6) drains, (7) conduit box, (8) lead opening, (9) external fan, and (10) flame arrestor. The external appearance is about the same. **(FIGURE 1)**

Will new insulations eliminate need for explosion-proof motors? No! Here is why.

BECAUSE OPEN-TYPE MOTORS are used in so many applications where formerly more protection was required, it is natural to question the need for explosion-proof enclosures for motors in hazardous areas.

Modern cage-type induction motors have windings that are so completely sealed that moisture or even oil cannot penetrate the insulation. There is no commutator or slip rings to spark in these motors and yet explosion-proof enclosures are required in certain locations. Reappraisal of the application of motors in hazardous areas has been one result of this focus of attention on enclosures.

There are many possible causes of sparking, arcing or heating in a motor that make an open type motor unsafe in certain hazardous areas. Some of these causes are:

1. Winding failure resulting from lightning or switching surges, overheating, starting high inertia loads or too frequent starting.

2. Mechanical damage to motor such as a cracked cage bar or end ring, or a bearing failure.

3. A small bur in the air gap which can become incandescent during start up.

4. Overload protection not covering possible single phasing or system over or under voltage conditions.

The application of electrical drives in hazardous areas is defined by various codes, insurance underwriting groups, and existing standards. The National Electrical Code, NEC, defines explosion-proof as follows: "Enclosed in a case which is capable of withstanding an explosion of a specified gas or vapor which may occur within it, and of preventing the ignition of a specified gas or vapor surrounding the enclosure by sparks, flashes or explosion of the gas or vapor within, and it must operate at such an external temperature that a surrounding flammable atmosphere will not be ignited thereby." Such motors are required in areas defined as hazardous by the NEC. Depending on the type of hazard, there are two classes: Class I, explosive gases and vapors; Class II, explosive dusts.

Of most concern in motor applications are the dangers of explosion and fire in Class I locations where hazardous accumulations of flammable gases or vapors can accumulate in the course of normal operations. This includes such industrial areas as oil fields, oil and gasoline refineries, oil and gas pipe lines and pumping stations, paint and pigmentation plants, painting booths, chemical plants and hydro-carbon gas manufacturers.

Applications for the Class II or dust ignition-proof motors are basically determined by the atmospheric hazard of dust explosion or ignition as compared to vapors. The successful operation of this type of enclosure is to exclude ignitable amounts of dust and to prevent sparks from causing an explosion of the atmosphere of a specific dust.

Conditions grouped by magnitude of hazard

The Underwriters' Laboratories have tested and grouped various atmospheric mixtures commonly experienced in Class I and Class II locations on the basis of their hazardous characteristics.

These groups are listed in descending order of magnitude of hazard involved for Class I:

Group A — Acetylene.

Group B — Hydrogen, or gases or vapors of equivalent hazard such as manufactured gas.

Group C — Ethyl-ether vapors, ethylene or cyclopropane.

Group D — Gasoline, hexane, naphtha, benzine, butane, propane, alcohol, acetone, benzol, lacquer, solvent vapors or natural gas.

Class II motors, of similar construction to those used in Class I areas, are required in atmospheres containing combustible dust. They include:

Group E — Metal dust, including aluminum, magnesium and their commercial alloys.

Group F — Carbon black, coal or coke dust.

Group G — Flour, starch or grain dust.

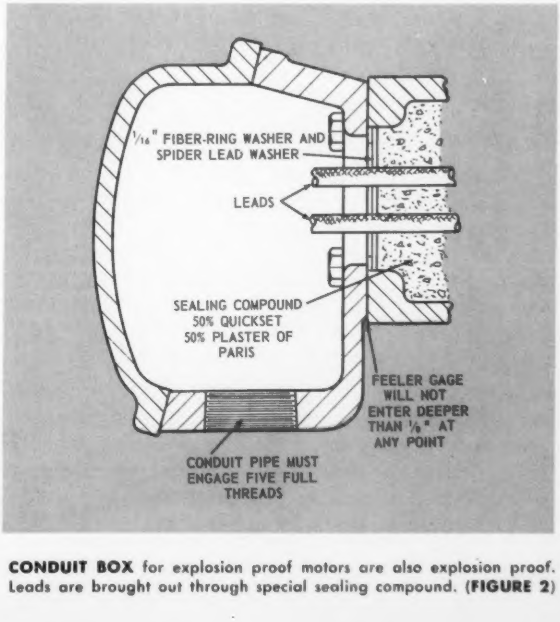
Hazards are further defined by the National Electrical Code as Division 1, where the hazard exists continually, or Division 2, where the atmosphere may become hazardous under unusual conditions but is, for the most part, hazard free. Considerable inconsistency has developed in the classifying of locations as Division 1 or 2. Motor manufacturers sometimes furnish a special-hazard class machine for application in a plant location where the motor is surrounded by machines or devices not meeting the conditions required. Local inspection codes may be the reason, particularly where revised codes do not apply to equipment already installed. In highly electrified industries, keeping the entire plant up to date as code revisions are made can get to be a real problem. However, safety of employees and the community, as well as economic factors, must be considered.

Some state or local codes permit defining a motor as hazard-proof purely on the basis of local inspection but most areas require the Underwriters' Label. The UL assures the user and his insurance underwriter that the motor has been built to Underwriters' standards and should not rupture, should an explosion or fire take place either inside or outside its enclosure. Further, if an explosion or fire occurs inside the enclosure, it should not set off an explosion or fire in the ambient atmosphere.

Totally enclosed and explosion-proof motors are compared

The Underwriters' Laboratories have established construction standards for explosion-proof motors. These can be pointed out by comparing standard totally enclosed fan cooled, and explosion-proof designs in NEMA sizes. The following features, correspond to the numbers in Figure 1. These features are:

1. *Yoke*—The yoke must contain an internal explosion without rupturing. For economic reasons the same design casting is generally used for both types of machines, with longer fits machined into the explosion-proof casting. The difference lies in the tensile strength of the iron used in the castings with that used for explosion-proof motors having greater strength.



CONDUIT BOX for explosion proof motors are also explosion proof. Leads are brought out through special sealing compound. **(FIGURE 2)**

2. *Bearing housing* — As in the case of the yokes, the difference lies in the higher tensile strength of the iron used in the explosion-proof design. In addition, more bolts are sometimes specified for securing bearing housings on explosion-proof types.

3. *Fits* — All fits must be metal-to-metal in explosion-proof machines. No gaskets may be used to make joints tight. Fits in explosion-proof machines are longer, and held to closer tolerances than in other TEFC motors.

4. *Bolts* — Greater tensile strength is specified for bolts used in explosion-proof motors.

5. *Holes* — There can be no holes through the enclosure of an explosion-proof motor, even where that opening may be closed by a removable screw or plug. An exception, of course, is made in the case of openings for shaft extensions, which are protected by flame arresters. Screws or bolt fasteners do not lead to the motor interior, but terminate in blind holes that will not permit flame passage if the screw is not replaced after removal.

6. *Drains* — On standard totally-enclosed motors, easily removed pipe plugs are provided in the bottom of the frame or bearing end-shield. These can be taken out periodically to check for accumulations of condensed moisture. To eliminate the human factor of forgetfulness in replacing such plugs, drains for explosion-proof motors must be of an automatic type approved by the Underwriters' Laboratory and permanently brazed to the enclosure.

7. *Conduit box* — The conduit box of an explosion-proof motor must be a separate enclosure, heavier in cross-section than a standard conduit box. Like the motor enclosure, it must be able to withstand internal explosions without rupturing or having joints become loose. Longer machined fits are utilized and the conduit opening is tapped to provide a specified minimum number of threads in engagement. No gaskets are used between the conduit box and yoke, nor between the box and its cover.

8. *Lead opening* — The lead opening in the frame of an explosion-proof motor must be sealed, and the seal plug backed up in such a way that the force of internal explosion cannot drive it out of position. Washers are held in place by a smaller sized conduit box opening, such as shown in Figure 2, preventing the filler material from being blown into the conduit box should an explosion occur inside the motor enclosure.

9. *External fan* — The external fan of an explosion-proof motor is generally of a non-ferrous material, which will not cause a spark if it strikes or is struck by some object. Aluminum, bronze, and plastics are commonly used.

10. *Flame arrestor* — The inner bearing cap of an explosion-proof motor serves as a flame arrestor. It provides a long close-running clearance over the shaft to quench the flame of an internal explosion.

It is important to note that the difference in construction between explosion-proof and standard TEFC designs is mechanical only. For a given rating the electrical design is the same for both.

Construction requirements for explosion-proof motors larger than NEMA standard frames are similar. Figure 3 shows a cross-section through a 1250-hp Underwriters' approved motor. It is tube-cooled, as are most larger ratings. The group of these motors, shown in Figure 4, is installed in a petroleum pipe-line pumping station. Motors of this type are available in any size or rating normally required by industry.

Underwriters' approved motors bear an official label, such as shown in Figure 5, identifying the hazardous area in which the machine can be operated in safety. The right to apply this label is not easily earned. An initial step in gaining approval is to submit all detailed drawings of the motor construction to the Underwriters' Laboratories. These are reviewed for compliance with construction requirements, considering clearance tolerances, pressure levels, and factors of safety. Once drawings are approved, the motor is built and submitted to the Laboratories for physical tests involving the presence of specific gases or vapor and air mixtures over the range of flammable or explosive concentrations.

A typical test series, made by the Underwriters on a 1250 hp, 1800-rpm rating, demonstrates the thoroughness of these procedures. Before testing, the sample motor casing and the conduit box are tapped for supply lines carrying explosive mixtures, and for electrical connections

INTERNAL AND EXTERNAL AIR are separated by flame barriers and close shaft clearances in typical higher rated motor. Construction is heavy enough to contain an internal explosion. **(FIGURE 3)**

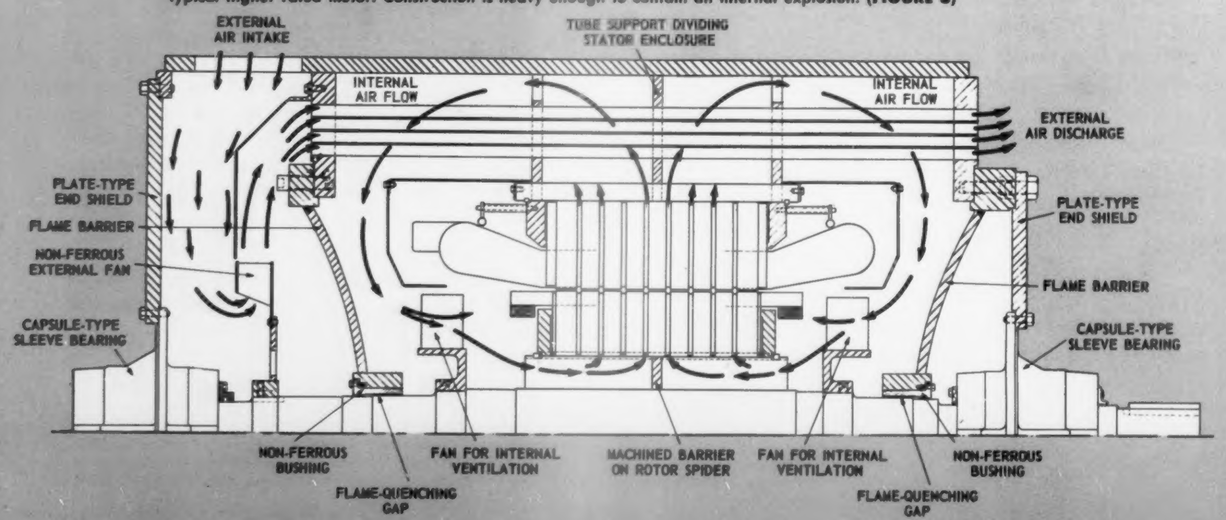


TABLE I
EXPLOSION TEST DATA — GASOLINE VAPOR-AIR MIXTURES, 1250 HP MOTOR

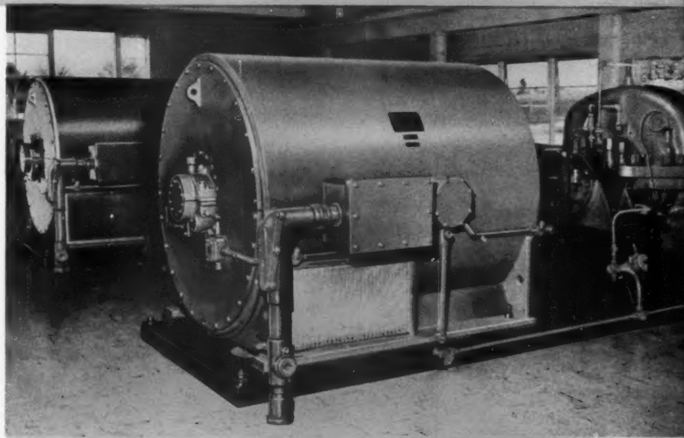
Test No.	Per Cent by Volume of Gasoline Vapor in Mixture With Air	Initial Temp of Device (Room) C	Status of Motor	Location of Spark Plug in Motor	Maximum Explosion Pressure PSIG	
					DE†	ODE††
1	1.50	24	Not running	DE	60	76
2	1.53	24	Not running	DE	85	32
3	1.73	24	Running	ODE	15	132
4	1.79	22	Running	DE	130	48
5	1.88	22	Running	ODE	30	136
6	1.99	22	Running	DE	140	28
7	2.02	22	Not running	ODE	25	128
8	1.64	22	Not running	DE	105	60
9	1.67	22	Not running	DE	70	24
10	2.52	22	Not running	DE	75	36
11	2.97	22	Not running	DE	75	44
12	1.97	25	Running	DE	165	—
13	2.18	25	Running	ODE	20	164
14	2.21	25	Running	DE	148	16
15	2.23	25	Running	ODE	30	152
16	2.21	25	Running	DE	175	16
17	2.10	25	Running	ODE	40	172
18	1.91	25	Running	DE	150	16
19	2.01	25	Running	DE	150	16
20	2.09	25	Running	DE	165	20
21	2.26	25	Running	DE	135	16

TABLE II
EXPLOSION TEST DATA — GASOLINE VAPOR-AIR MIXTURES CONDUIT BOX

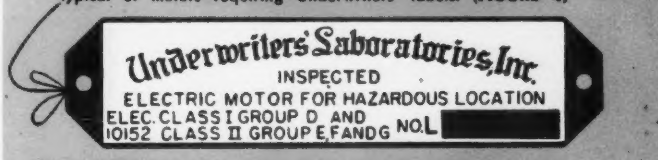
Test No.	Per Cent by Volume of Gasoline Vapor in Mixture With Air	Initial Temp of Device (Room) C	Maximum Explosion Pressure PSIG
1	1.73	24	108
2	1.70	24	115
3	1.80	24	108
4	1.93	22	115
5	2.13	22	126
6	1.99	22	124
7	2.03	22	121
8	2.23	22	122
9	2.33	22	112
10	2.40	22	104
11	2.66	22	97
12	2.94	22	77
13	2.14	22	115
14	2.07	22	112
15	2.20	22	119

† DE — Drive end of motor
†† ODE — End of motor opposite drive

to spark plugs and pressure recording devices. Explosive mixtures of gasoline vapor and air, prepared in special carburetors, are fed into test chambers, replacing the original air. Samples of the explosive mixture are taken for analysis. Inlet and outlet connections are sealed, and the mixtures ignited by means of spark plugs. Tests are conducted both with the motor running and at standstill. During each test the devices are observed carefully for the appearance of flame or sparks at joints and shaft openings. A summary of test results on both motor and conduit box is presented in Tables I and II.



PUMP MOTORS on oil pipeline rated 1250 hp, 1780 rpm, are typical of motors requiring Underwriters' labels. (FIGURE 4)



UNDERWRITERS' LABEL for hazardous locations is indication that suitability of design has been thoroughly checked and tested. (FIGURE 5)

Other measures may be dictated by economics

Economic considerations are important in considering whether an approved-type enclosure is specified, or if other measures for protection will be taken. Explosion-proof ratings generally cost more than equivalent open types. This has given impetus to the reclassification of areas to Division 2. An open type, 5500-hp cage motor driving a compressor in a cracking plant area classified Division 2 is an example of this reclassification. It is top ventilated with air intakes and exhausts located in a special sound-absorbing housing. Significantly, although the motor itself is a conventional open type, the conduit box and other electrical devices in the motor area are classed as explosion-proof.

In other instances where a maximum of safety is desired without the high cost of an explosion-proof type enclosure, pressurized enclosures have been applied, on the principle that with positive pressure within the enclosure, all leakage will be outward, and explosive gases cannot accumulate. Enclosures purged of explosive gases and ventilated with uncontaminated air introduced through pipes or ducts have been used in some instances.

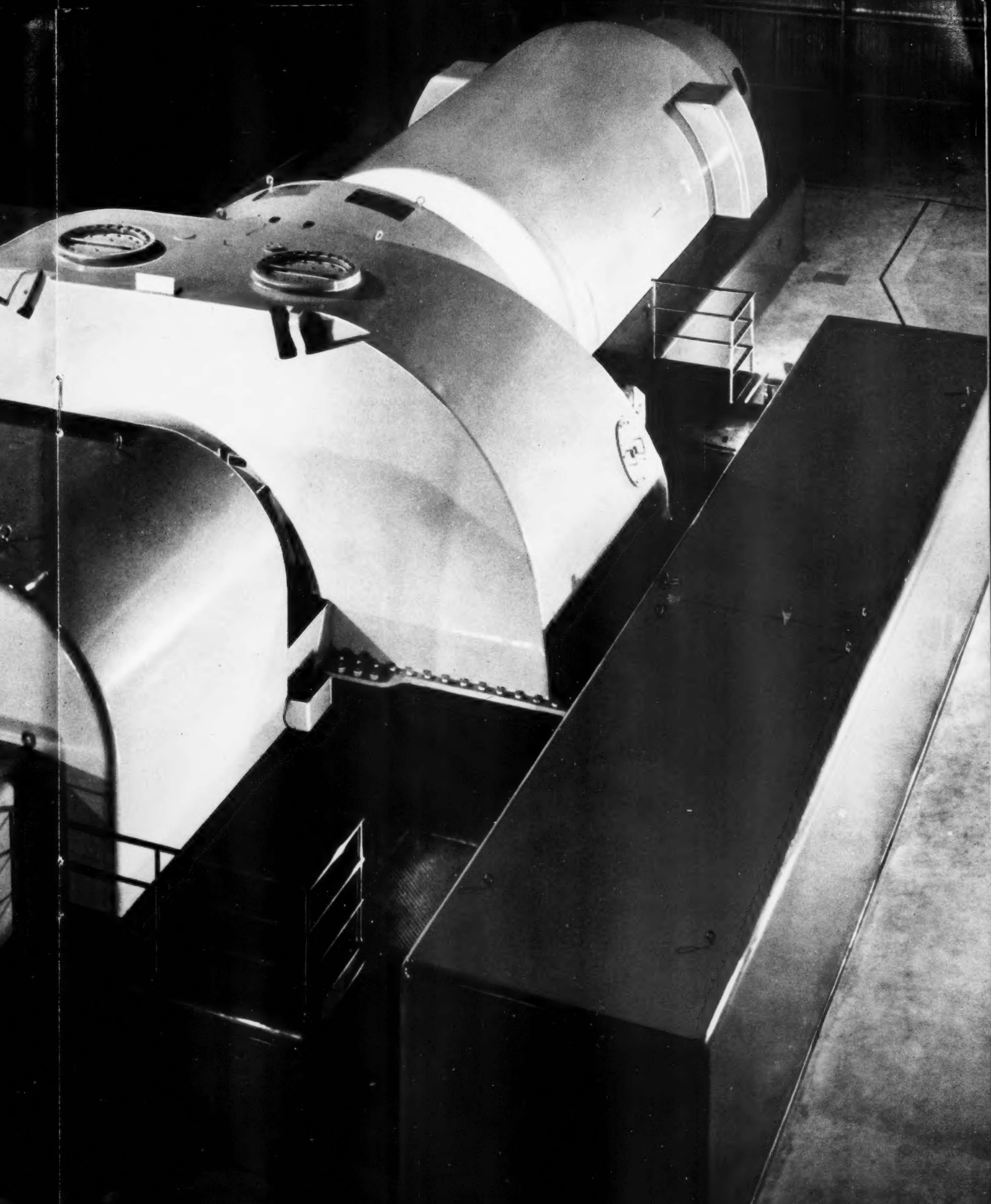
A more elaborate scheme involves a system for maintaining above-atmospheric pressure inside a motor enclosure with inert nitrogen gas. This arrangement requires a gas-to-water heat exchanger, as well as devices such as gas manifolds for making sure that positive pressure is constantly maintained while the motor is in operation. Because of the possibility for failure of components, pressurized systems are not approved by the Underwriters' Laboratories. They have, however, proved highly successful in operation, and have generally been sanctioned by insurance inspectors and local ordinances for all but the most hazardous of conditions.

Only careful assessment of actual or potential hazards in an area where motors are to be installed can govern the choice of enclosure. Economic factors cannot influence motor selection at the expense of safety. ◆

HIGHEST-RATED, SINGLE-FLOW, 1800 rpm, steam turbine-generator unit is dynamic link between the Enrico Fermi fast breeder reactor and Detroit power users. A unique feature of this turbine is its side cross-unders which double as steam reheaters to control exhaust moisture. Articles on pages 4 and 21 provide basic engineering information on this history making plant.

Allis-Chalmers Staff Photo by Michael Durante


ALLIS-CHALMERS
A-C



STORED ENERGY ADDS VERSATILITY TO POWER CIRCUIT BREAKERS

G. L. HOSSFIELD
Boston Works
Allis-Chalmers Mfg. Co.

Stored energy operators simplify control schemes and provide operating and maintenance savings.

ONE TYPE STORED ENERGY OPERATOR consists of a motor charged spring closing mechanism which is an integral part of the circuit breaker. Breakers with these operators have many practical applications.

As soon as circuit breakers were furnished with electrical operation, the need arose for an operator which did not require the investment of a high capacity battery for small installations such as industrial substations. A stored energy operator was developed about 35 years ago to satisfy this need. A universal motor charged an assembly of springs, which, when released by a latch mechanism, would close the breaker. The operator was very popular in industrial substations and other locations where there was no economic justification for a relatively large operating battery.

This early version of the stored energy operator came when electrical control circuits were in their infancy. When the copper oxide rectifier was applied to breaker closing circuits, the rectifier-solenoid operator easily won acceptance over the complex of linkages and mechanical controls of the spring operator.

Present relays and control schemes have, however, simplified greatly the problems encountered in the design of an operator. Modern stored energy operators, such as shown in Figures 1 and 2, afford simplified design with less cost and less maintenance compared to their predecessors of 35 years ago.

Figure 2 shows the small universal type operating motor as well as the powerful closing springs which it charges.

Figure 3 shows schematically the operation of the stored energy device. The high torque universal motor operates through the gear box to rotate the gears and drive the eccentric arm. This arm turns the rocker arm, A, to rotate the shaft. The cam rotates with the shaft and moves the spring plate against the force of the closing springs. When the springs reach the fully charged position, the release latch locks in place holding the springs in the charged position, and the motor is cut off by a limit switch.

The potential energy stored in the springs may be released by operation of the release latch which is actuated either manually or electrically by the release coil. When the release latch is driven away, the spring plate is forced against the cam and the shaft rotates along with the rocker arm, B, and a pin on the rocker arm, B, engages the rod through a slotted hole and pushes the rod up to close the breaker.

As soon as the springs have closed the breaker, the limit switch energizes the motor circuit and the motor charges the springs for another closing operation.

Control is adaptable

The control circuitry of circuit breakers equipped with stored energy operators consist of three individual elements; the spring charging motor, the closing coil or release coil and the trip coil. Much of the versatility inherent in this operator stems from the fact that these three elements are separate and can be connected to different supplies at different voltages without added circuit complexities.

The first element, the spring charging motor, is a small universal ac-dc motor which charges the energy storing springs in approximately eight seconds. Different motors can be obtained to suit a variety of voltages either ac or dc.

The release coil and breaker trip coil are both used to trip latches and are, therefore, of similar design and can also be obtained for various voltages ac or dc. Since these three elements perform separate functions they are separate entities and can be supplied from different sources. That is, the charging motor and release coil could be supplied at 230 volts ac to conform with existing controls at a particular installation and the trip coil could be 48

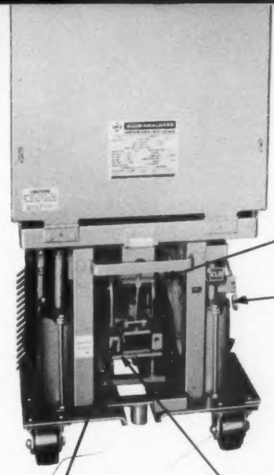
volts dc. Or, the charging motor could be 230 volts ac and the release and trip coils both be 48 volts dc. In addition, because of the small current requirement of the charging motor, 7 amps at 125 volts dc, as compared to that of the solenoid operator rated 50 to 100 amps or more at 125 volts dc, a low capacity battery could be used for all three elements.

Where a high capacity dc bus is not feasible, as in an industrial substation, the charging motor's small power requirement makes it practical to supply the control power from a small battery, usually 48 volts, with a floating charger. This scheme has been applied when the utility is curtailing its dc power supply. It is also applicable when it is desirable to eliminate a closing power transformer for a savings of either cost or space. Most applications to date have been for the 48-volt dc motor with 48-volt dc release and trip coils.

In some small or remote substations it is feasible to furnish a 115 volt ac charging motor to be supplied from the station auxiliary supply or from a transformer on the incoming bus. The release and trip coils can be supplied from a small battery at 24 volts dc. If preferred, however, these coils could also be fed from the same 115-volt ac supply as the charging motor, but through a single capacitor trip device.

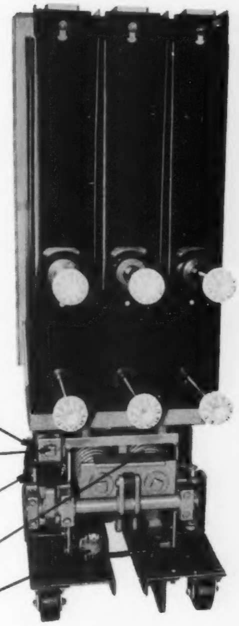
Capacitor trip device can be used for closing breaker

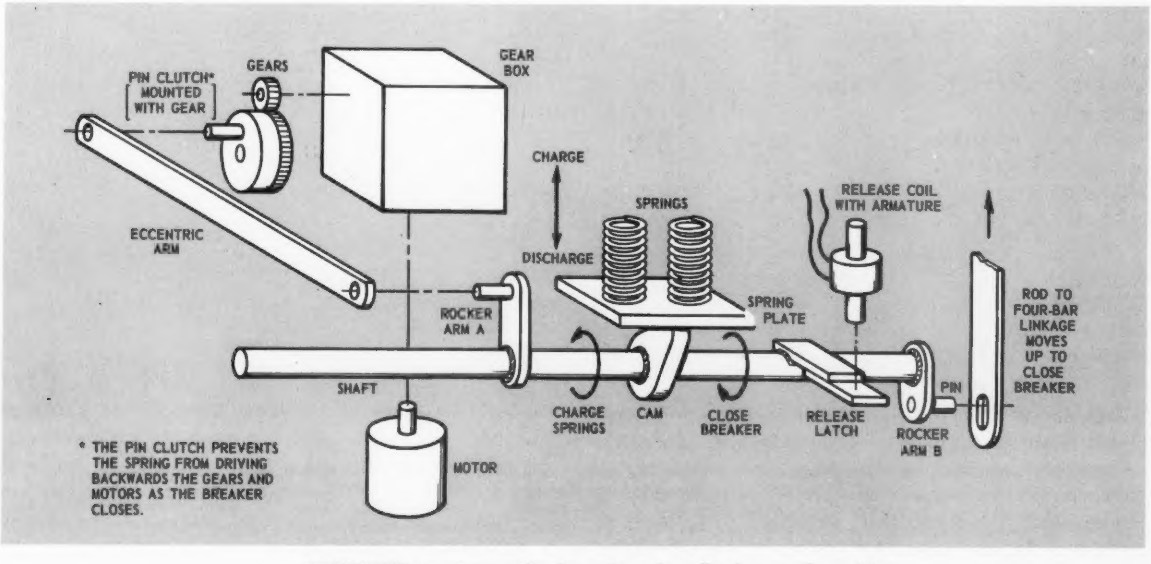
When using a capacitor trip device, the release coil of the stored energy operator functions in the same manner as the breaker trip coil in that it operates a latch which, in turn, releases the stored energy of a spring. The spring may be the opening spring for the trip coil or closing spring for the close coil. Thus, a capacitor trip device, designed to energize the trip coil should perform equally as well energizing the close coil. If the two coils have the same voltage rating, a single capacitor trip device could be used to both close and trip the breaker.



STORED ENERGY OPERATOR simplifies the control of switchgear type 250,000-kva air magnetic circuit breakers. **(FIGURE 1)**

SMALL UNIVERSAL MOTOR charges powerful springs which when released produce high speed breaker closing. **(FIGURE 2)**





MECHANISM is set in motion by action of small release coil requiring low control power which can be obtained from various sources. **(FIGURE 3)**

A frequent problem is the operation of switchgear during abnormal or emergency conditions involving the loss of station control power. Power circuit breakers are not designed to be energized with the maintenance closing handle, and, with the loss of normal control power, there is no convenient way in which the solenoid operated circuit breaker can be closed. A unique feature of the stored energy operated circuit breaker is that the energy storing springs can be manually charged while the breaker is in the switchgear cubicle. It is then a simple matter to manually close the breaker, energizing the line. If the circuit breaker to be closed were furnished with a 125-volt dc charging motor, close and trip coils, the motor could be temporarily connected to a 115-volt ac supply and charged. The closing coil and trip coil could also be energized from the 115-volt ac, but through a standard capacitor trip device.

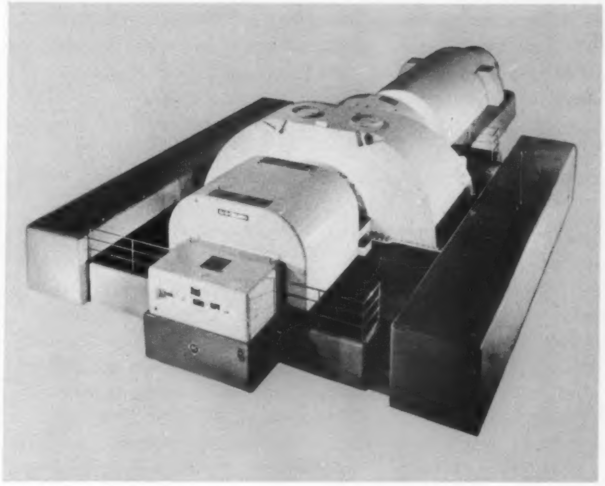
A charged spring requires very little accelerating time to acquire its final closing velocity, and a circuit breaker equipped with a stored-energy operator will close in 5 to 7 cycles as compared with 18 cycles for a breaker equipped with a solenoid operator. This high speed makes it practical to provide a rapid transfer of load from one source to another in the event of a power failure.

Stored energy closing of circuit breakers promises to provide the answer in many applications in which only limited or unreliable control power is available. The control power requirements for present designs are low and simple economical sources can be readily provided. Closing and tripping arrangements are easily adapted for capacitor trip devices.

Because of this adaptability to many modern control schemes, stored energy closing is expected to gain wide acceptance. ◆

REFLECTING TRENDS to larger capacities and higher operating pressures, these two tray-type deaerating extraction heaters are each rated 2,328,000 lbs/hr effluent and are designed for 150-psig inlet steam. They will remove corrosive gases from feed-water for 310-mw units 3 and 4 at Southern California Edison Company's outdoor Alamitos Station. Internal parts of the deaerators are of type 304 stainless steel for protection from corrosion. Two similar units, of equal size, will be furnished for Edison's Etiwanda Station. Each will have a storage capacity of 30,000 gallons.

NEW TURBINE DEVELOPED FOR ENRICO FERMI PLANT



B. S. HERBAGE and C. L. RINGLE
Thermal Power Department
Allis-Chalmers Mfg. Company

Nation's first commercial breeder reactor plant posed unique turbine design and control problems for 150-mw unit.

NUCLEAR POWER REACTOR RESEARCH and the development of better generating and operating techniques are the primary objectives for the Enrico Fermi plant.

The "breeder" type reactor will be operated at various controlled heat generation outputs. This heat is transferred via three sodium-heated steam generators to produce non-radioactive steam initially at 575 psig — 742 F and ultimately at 850 psig — 780 F. During the investigation of various load conditions, the output steam, in quantities up to rated design, must be handled and dissipated through bypass valves, dump-valves or expanded through the turbine-generator unit into its condenser. Since the sodium heat transfer loops and the steam-generator cycle have thermal inertia, rapid steam demand changes must be minimized. Likewise, the reactor output changes are accommodated through by-passing control or opening of the turbine-generator inlet-steam control valves to maintain system pressure within prescribed limits. During electrical load dumps and unit overspeeds, the control equipment must protect both the reactor and the turbine-generator unit.

The large volumetric flow required to produce 150,000 kw, the need for moisture removal, and the unusual control features associated with the reactor, were the main design problems.

The steam turbine-generator is an 1800-rpm tandem-compound single-flow unit consisting of reaction type high-pressure and low-pressure turbines driving a conventional 185-mva hydrogen-cooled generator. A separate front steam chest manifold mounted below the operating floor and steam reheaters located at each side of the turbine are special features of this unit.

Control is based on pressure variation

The steam system control is essentially based on sensitivity to steam pressure variations. To achieve the desired operating flow and pressure stability, a steam-system pressure-control center with pneumatic outputs positions the various bypass valves and the turbine steam inlet control valves. The system is shown in Figure 1.

Essentially, the output of the steam generators is utilized by the steam turbine during normal operation. The turbine inlet control valves determine this flow under direction of the pressure-control center. Increased reactor outputs, not normally absorbed by the turbine, would result in excess steam-system pressure rises. This excess steam is controlled by the large dump valves (A) and would spill into the large No. 4 deaerating heater of the regenerative system. Unloading steam valve (C), in turn, relieves this heater into the turbine condenser. The temperature control steam valve (B) provides warming steam to correct for low No. 4 heater temperatures.

Discontinuities in steam flow during abnormal operating conditions such as: a turbine-generator electrical load dump, emergency trip-outs or excessive reactor output swings, initiate a relief action at the bypass valves (A) and (B). Steam header pressure abnormal variations and anticipatory signals from the turbine speed-control servo-system, hydraulically stimulate the pressure control-center to direct immediate dumping action at the bypass valves (A) and (B). The signal from the speed-control servo-system would result from a turbine trip-oil pressure decay

or a pressure decrease at the speed governor actuated pre-overspeed control. The reactor output controls are simultaneously activated for correction of steam-generator output.

Modified turbine steam inlet control used

The turbine control consists of modified conventional steam inlet valves and governor servo-system, as shown in Figures 2 and 3. Essentially, the turbine control provides manual and speed-governing regulation of the steam inlet control valves for turning-gear operation and synchronizing at rated speed operation. The servo-system governor levers incorporate an initial pressure regulator which is positioned by the pressure-control center to provide steam inlet valve positioning control based on header-pressure variations after the unit is on the line. Thus, the governing system is essentially mechanical-hydraulic, providing duplex control from both steam pressure and unit speed.

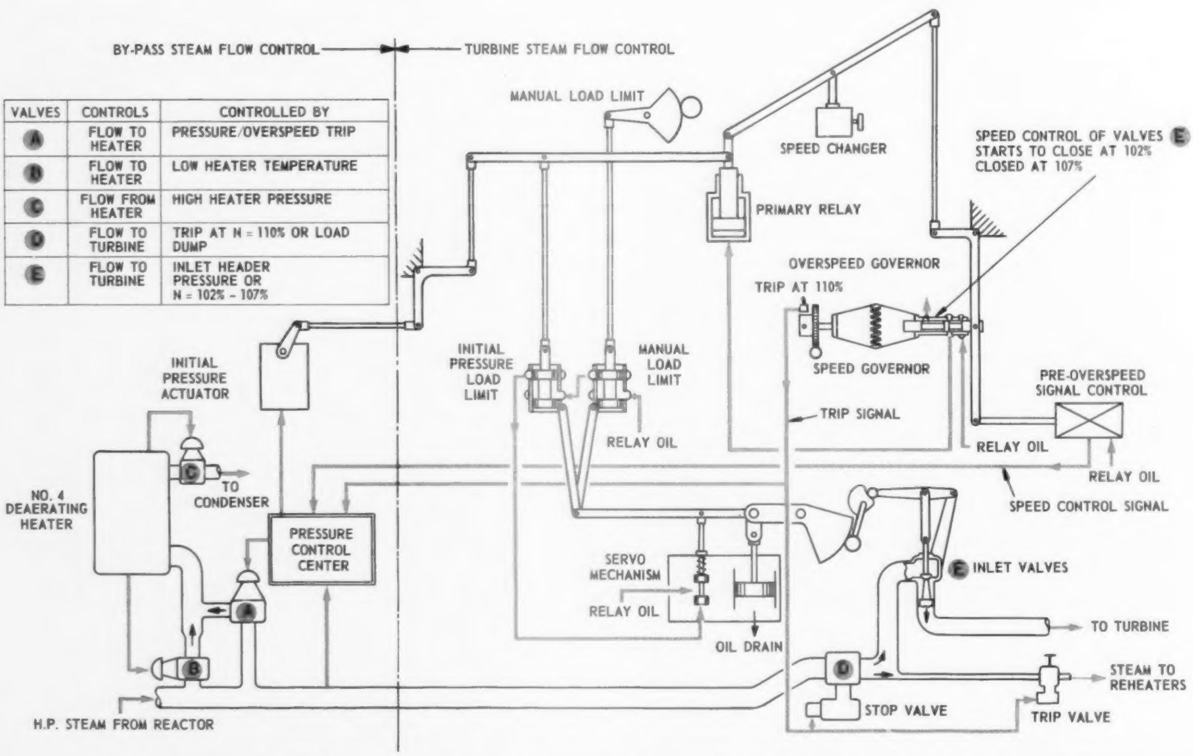
The steam inlet control equipment is built in the form of a manifold and mounted below the floor in front of the turbine. Inlet steam enters through two parallel 14-inch trip stop valves which are oil pressure opened and spring closed. The stop valves feed the manifold and two cam-positioned 7-inch steam inlet control or governing valves, opening successively to feed the turbine reaction inlet chamber. The spherical plug-type inlet valves are 12-percent chrome, with Malcomized stems. They discharge through long diffuser seats into the turbine inlet pipes.

The inlet control valve cam shafts are driven by a pinion and gear segment positioned by the main servo-mechanism. The speed governor is a conventional super-sensitive type and is helical-gear driven from the turbine shaft. Since the turbine in normal operation is under initial pressure control, the speed governor only controls the valves after a 2-percent overspeed is reached and then functions as a pre-emergency governor. A conventional 10-percent overspeed trip emergency governor, integral with the high-pressure turbine shaft, is incorporated. A 6-inch auxiliary manually operated throttle trip valve bleeds steam from the steam manifold to provide heating steam for the turbine's integral side-crossover reheaters. All stop valves can be manually exercised, one at a time, while the turbine is in operation to assure that they will function properly in emergency. The two main stop valves can also be remotely opened and closed from the control room, for "puff" warming during startup and for routine exercising after the unit is on the line.

Shaft pump supplies lubrication and seal oil

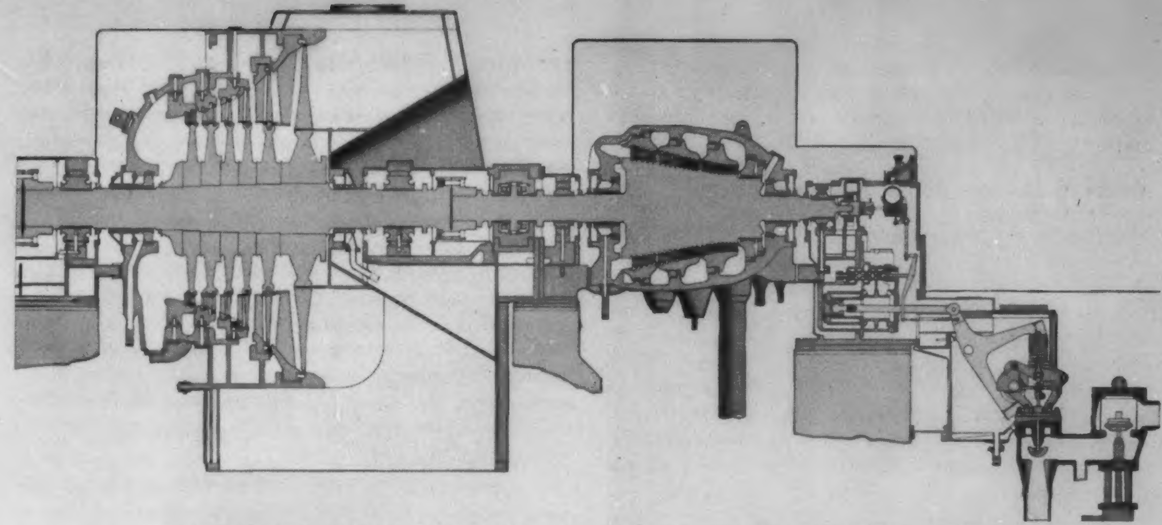
The oil pumps, oil-cooling equipment and oil reservoir are of conventional design. The main shaft pump, shown in Figure 2, is an 1800-rpm centrifugal pump delivering approximately 700 gpm at 150 psi. The pump is primed by a turbo-primer located in the oil tank.

The water-cooled heat exchangers, with a constant flow transfer valve, cool the oil before it enters the intermediate pressure system. Demand-type intermediate pressure and bearing pressure regulators control the source



VALVES	CONTROLS	CONTROLLED BY
A	FLOW TO HEATER	PRESSURE/OVERSPEED TRIP
B	FLOW TO HEATER	LOW HEATER TEMPERATURE
C	FLOW FROM HEATER	HIGH HEATER PRESSURE
D	FLOW TO TURBINE	TRIP AT N = 110% OR LOAD DUMP
E	FLOW TO TURBINE	INLET HEADER PRESSURE OR N = 102% - 107%

ENRICO FERMI PLANT steam flow and control system is based on sensitivity to steam pressure variations. **(FIGURE 1)**



TANDEM-COMPOUND single flow turbine for Enrico Fermi atomic power plant is rated 150 mw, 1800 rpm. Low pressure turbine uses 46-inch last row blades and has its steam path arranged back to back with the high pressure turbine to balance blading thrust and to reduce balance piston size. (FIGURE 2)

pressure of generator hydrogen-seal oil and unit bearing oil. The hydrogen-seal oil is filtered and its pressure entering the seals is controlled by a regulator system located at the generator. A conventional complement of ac auxiliary pumps, with dc emergency back-up pumps, is incorporated.

Steam generators heated prior to startup

The system design is such that the steam generators will be "steamed" before the turbine is started. While the steam generators are being brought up to pressure and temperature, their steam is short-circuited by means of the bypass valves into the large No. 4 heater. The bypass valves will also be open while the turbine-generator unit is being brought up to speed, synchronized and put on the line. Once on the line, load control of the unit will be transferred from the turbine speed-governor control system to the pneumatic control system. The pneumatic system controls turbine steam inlet valve opening to maintain constant pressure in the steam lines from the steam generators which depend on variable reactor output.

Under these conditions of loading and system-steam utilization, the turbine speed control speed changer will have been pre-set at a pre-emergency position and the speed governor will not interfere with the inlet valve control system during frequency deviations of less than 2-percent.

Load dumps or a breaker electrical trip action, following a fault, will result in a speed increase of the turbine. At 102-percent speed and above, the speed governor system will act as a pre-emergency governor and again take over to close the steam inlet control valves. Also, the pressure signal from the pre-emergency control valve will activate the pressure control center to initiate steam-system dump valve action. A trip-out action of the turbine controls will initiate a similar action. After stability has been re-established, and the fault cause cleared, the unit can again be synchronized under speed-governor controls.

Turbine selected for large volumetric flow

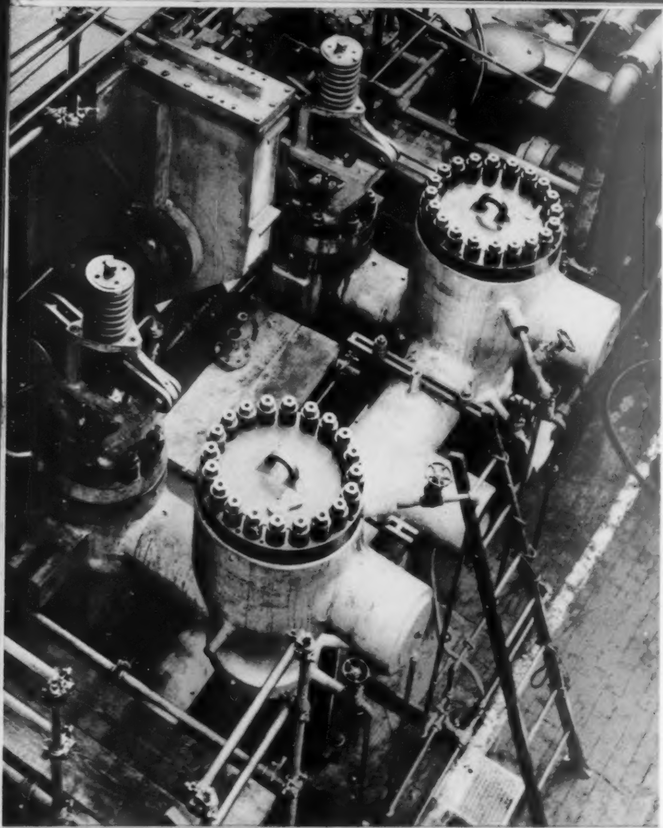
The 1800-rpm speed was selected to handle the large volumetric flow and to make use of standard 46-inch exhaust blades, the largest blades in use at this time. Cross-section of the unit, Figure 2, shows the single-flow reaction type high-pressure turbine and the single-flow low-pressure turbine.

Steam flows from the inlet valves in the below-floor front steam chest through flexible inlet bends to the high-pressure turbine and from the high-pressure turbine to the low-pressure turbine through steam reheaters flanking the unit. In this way, the steam reheaters act as side-crossover pipes in addition to serving their function of raising the superheat to the low-pressure turbine inlets.

Heavy wall sections in the higher temperature regions are kept to a minimum to maintain conservative thermal stress levels. For this reason the steam chest manifold was mounted as a separate element below floor in front of the unit rather than being made an integral part of the high-pressure cylinder. This location of the steam chest manifold shortens the main steam piping. As the steam to the unit is non-radioactive, no protective shielding is required at the No. 1 pedestal operational area over the below-floor steam chest.

The steam chest combines two stop valves, two inlet control valves, a reheater supply valve, and an interconnecting T-piece. Its manifold is of all-welded construction which, when rigidly anchored, can absorb maximum forces and moments from the main steam piping without transmitting these to the high-pressure cylinder.

The high-pressure turbine is shown in Figure 4. It incorporates straight reaction blading which is ideally suited for the pressure, temperature and volumetric flow. Although many straight reaction high-pressure machines



BELOW-THE-FLOOR front steam chest has two stop valves and two inlet control valves governed by adjacent torsion shafts from valve actuating mechanism. Steam chest is of welded construction. (FIGURE 3)

ENRICO FERMI TURBINE initial pressure regulator is at upper right corner of the pedestal shown during shop assembly. Steam forces in high pressure cylinder are absorbed by massive linkage between high pressure cylinder and low pressure exhaust casing. The 46-inch blading, not shown, was installed during erection. (FIGURE 4)

have been built no existing modern design could be readily adapted to this application. Therefore, a new high-pressure turbine was designed to advanced concepts. Centerline support is used to maintain radial sealing clearances throughout. Diffused and controlled exhaust passages beyond the last stage of blading minimize the pressure drop and consequently increase the efficiency. The inlets and outlets are located below the horizontal joint to reduce disassembly time during normal inspections of the unit. The outlet section is reinforced to withstand the steam separating forces between the high-pressure and low-pressure turbines. Since inlet temperatures are above the accepted range for carbon steel applications, the high-pressure cylinder was made of conventional 1¼-percent chromium, ½-percent molybdenum steel.

The low-pressure turbine is basically one-half of the same design used for 275-mw to 400-mw units now in operation or being designed for conventional plants. The design is based on a single-flow 46-inch exhaust blade, consistent with an exhaust pressure of 1-inch Hg absolute. Special features include the support section for the high-pressure cylinder, provision for an especially large thrust bearing, and structural reinforcement for resisting steam separating forces imposed by the high-pressure cylinder. Some conception of the over-all structural rigidity can be gained from Figure 4.

Reheater has novel design

The expansion line, Figure 5, shows the effect of the reheater in raising the superheat to the low-pressure turbine inlet. As the steam expands through the high-pressure turbine, as shown by line A to B, it approaches the saturation line. Without reheat, the steam, in which the last stages of low-pressure blading would operate, would have had an excessively high percentage of moisture. By reheating from B to C, the final moisture condition is then much improved at D, resulting in improved performance and desirable reduction of blade and cylinder erosion.

The reheaters shown in Figure 6 utilize cross-flow. The heating steam is obtained from the main steam inlet at ultimately 780 F and passes through the tubes from end to end, while the steam being reheated is channeled by a series of transverse, axial and spiral baffles to cross the tube bundle three times. This design allows the steam to enter and leave the reheater on the same side with a pressure drop roughly equivalent to that in a conventional crossover.

This reheater design is advantageous in not requiring separate moisture removal equipment at a later stage in the cycle or the addition of complicated large diameter piping and bulky equipment to the power plant. This alternative could also require large non-return valves to prevent overspeed in the case of an electrical load dump. The side-crossover steam reheaters improve the net efficiency of the unit, whereas moisture separators would reduce the efficiency.

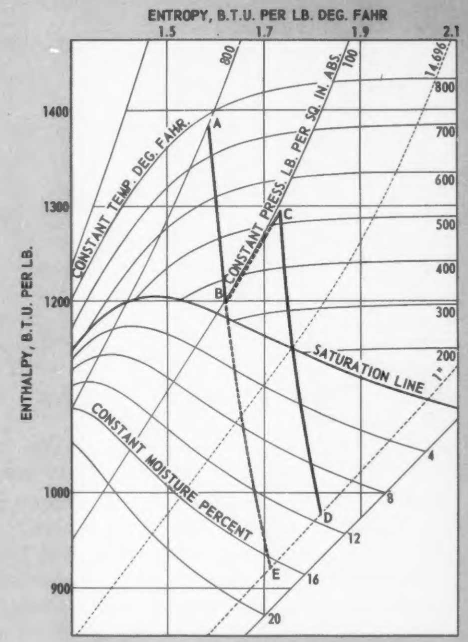
Thrust bearing design

The thrust bearing is located between the adjacent high

and low-pressure turbine journal bearings. Although the steam forces on the high and low-pressure turbines oppose each other, there is sufficient unbalanced thrust to warrant a large and reliable thrust bearing. An 8-shoe pivoted-pad bearing is used with load-equalizing leveling plates. High-tin-base babbitt is used for the shoe bearing surfaces. Thermocouples are located in three of the shoes on the loaded side and three shoes on the unloaded side. The thrust bearing was tested by artificially duplicating the unbalance in the high-pressure cylinder and, in effect, calibrating the thrust bearing metal temperatures to make them simulate a thrust load indicating device. The thrust bearing was tested to approximately one and a half times the expected design load.

At present, the turbine-generator is standing by waiting for the reactor-sodium-circuit-steam generator tests to be completed. The unit itself has been "checked-out" at the power plant using steam supplied by an auxiliary low-pressure boiler. Since load has been carried on the generator and the unit has been balanced, it is now ready for load tests on the entire plant.

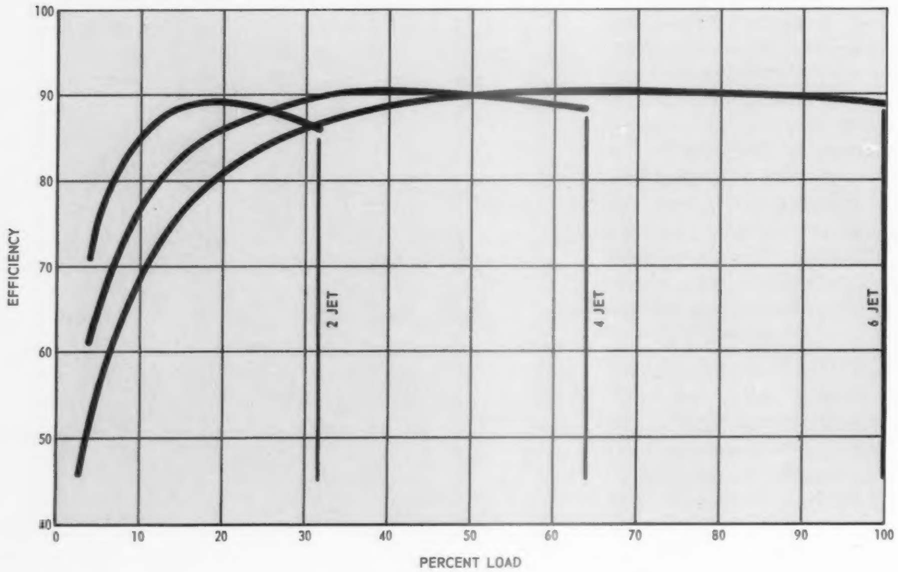
The turbine operating conditions in a "breeder" reactor plant differ from common fossil fuel steam plants. The design and control techniques developed for the Enrico Fermi turbine, plus the data and experience gathered from actual operation of the plant, promise to be helpful in planning and developing similar power plants as future need arises. It is expected that this plant, when placed in operation, using reactor-sodium-circuit-generated steam, will point the way to building other nuclear plants at less plant and fuel cost per kilowatt generated. ◆



REHEATING from B to C improves moisture condition. (**FIGURE 5**)

REHEATERS serving as side connection between the high and low pressure turbines are shown during the final stages of assembly at the Enrico Fermi atomic power plant. Heating steam passing through tubes, running length of reheaters, raises temperature of steam exhausted from high pressure turbine as it spirals past the tubing. (**FIGURE 6**)

Photo courtesy of Detroit Edison Company



GAINS in efficiency can be made at part load by reducing the number of jets in a multi-jet hydraulic impulse turbine. Two jets are used at greatly reduced loads in six jet turbine to increase efficiency. Gains with four jets do not justify added equipment. **(FIG. 1)**

HIGHER PART-LOAD EFFICIENCY FOR MULTI-JET HYDRAULIC IMPULSE TURBINES

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Operating at reduced output for sustained periods may justify automatic jet transfer control.

SAVINGS THROUGH GAINS in efficiency while operating at reduced loads may be made by closing some of the jet needles and operating with a few needles at relatively large openings.

The characteristic of a six-jet impulse turbine, given in Figure 1, shows an appreciable gain in efficiency can be obtained by proper control of the jets. Since at low part load the percentage of water saved is only a small percentage of the water required at rated turbine output, the equipment operating in conjunction with the governor, required to automatically transfer load from one group of needles to another group of needles, is only justified if the value of stored water is relatively high.

Changes in efficiency at power outputs greater than produced by two needles are minor and do not justify the cost of the additional auxiliary equipment for transferring power from one group of needles to another.

The method of transferring part load output from six needles to two needles with a minimum change in output of the turbine during the transition period provides an interesting problem.

An elementary hydraulic-mechanical diagram of a multi-jet impulse turbine control is shown in Figure 2. Only two needle controls, *B* and *C* are shown for simplicity. Any number of needle controls similar to *B* and *C* may be attached to the needle positioning shafts.

With the turbine connected to the system and the flyballs rotating at constant speed, any change in raise or lower position of the speed level mechanism position will cause the deflector servomotor to move proportionately to the relative change in speed level position.

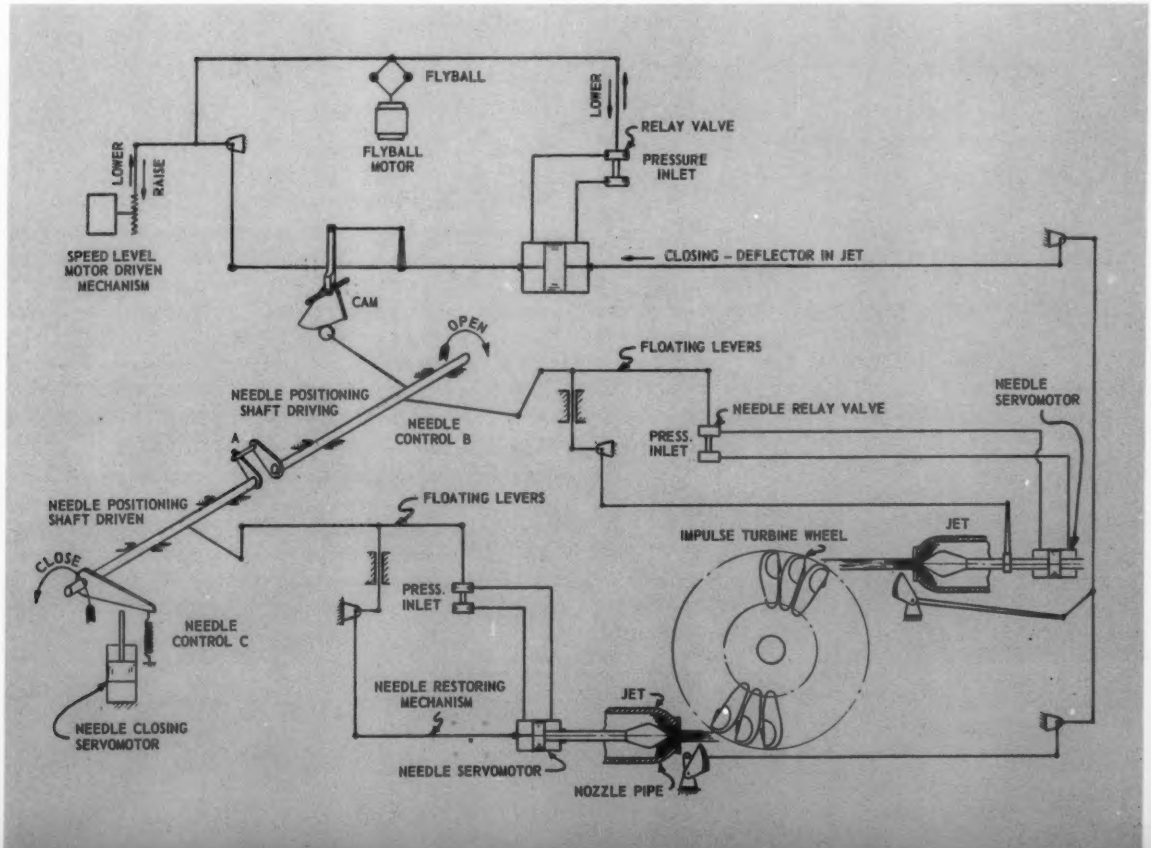
Assuming the needle positioning shaft is in one continuous section, with joint at *A* in Figure 3 fixed, the needle relay valves in needle control mechanism *B* and *C* will be lifted or lowered by an amount determined by movement of the cam mechanically connected to the deflector servomotor. This movement of the deflector servomotor will then cause a corresponding change in power output of the turbine through the resultant change in needle positions and all needles connected to the needle positioning shaft will be positioned equally.

If the needle positioning shaft is separated as at *A* with four needles of a 6-jet turbine connected to the driven section and two needle controls connected to the driving or cam actuated section, the driven section may be rotated counter clockwise by a hydraulic servomotor or other means, closing the four needles connected to the driven needle positioning shaft. The two needles controlled by the driving section of needle positioning shaft will then remain under control of the governor. If four needles are to be closed and the two remaining needles adjusted automatically to develop the same part load previously developed by six needles without excessive load fluctuations during the transition, two needles must be opened by an amount approximately equal to three times the stroke required to close four needles within the same time interval.

Needles transferred

Assuming the load on the turbine has been reduced to approximately 20 percent with six needles in operation, the load may be transferred from six to two needles by depressing start push button in Figure 3 or by other means of transmitting a signal to the control circuits. Relay 1 will seal in through the stop push button circuit and normally closed limit switch *a* which is open only when the driven needle positioning shaft is at the closed needle position. Control of the raise and lower speed level selector switch, *CS,* will be transferred to the needle control switch mechanically connected to the driving and driven needle positioning shafts through links *B* and *C.* The solenoid operated valve will also be energized through a normally open *2* contact causing the driven needle positioning shaft to be rotated counter clockwise, thus closing the four needles. The rate of closure of the four needles is predetermined by the adjustment of flow control valves in the needle closing servomotor hydraulic circuit. Rotation of the driven needle positioning shaft will close *R* contact. Speed level motor *R* circuit will energize the speed level raise circuit through a normally open contact *1* now closed. This action will cause the governor to rotate

HYDRAULIC-MECHANICAL control scheme of multi-jet hydraulic impulse turbine is simplified to show operation of jet needles for turbine control. **(FIGURE 2)**



the driving needle positioning shaft clockwise opening the two needles until movement of connecting rod *B* has opened contact *R*.

Again, referring to needle control switching, Figure 3, a clockwise rotation of the driving needle positioning shaft at a rate less than rate of rotation of the driven needle shaft will open *R* contact and close *L* contact. The speed level motor will then cause the driving section of the needle positioning shaft to rotate counter clockwise, arresting further clockwise movement of the driving shaft until contact *R* is again closed. The rate of driving-shaft rotation is therefore, always a function of needle closing servomotor movement.

Proper coordination between the rate of closure of the four needles and rate of opening of the two needles will result in the two needles opening by a series of very small intermittent incremental changes in the output of the turbine during the transfer period. The output of the turbine will then be nearly constant and free of large surges.

Linkage *B* and *C* is proportioned so that link *C* will have one third of the movement of connecting link *B*; therefore, when four needles have closed, the two needles will have moved toward open position by three times the amount of movement required to close the four needles from a reference established by the positions of six needles at the instant the needle transfer signal was received.

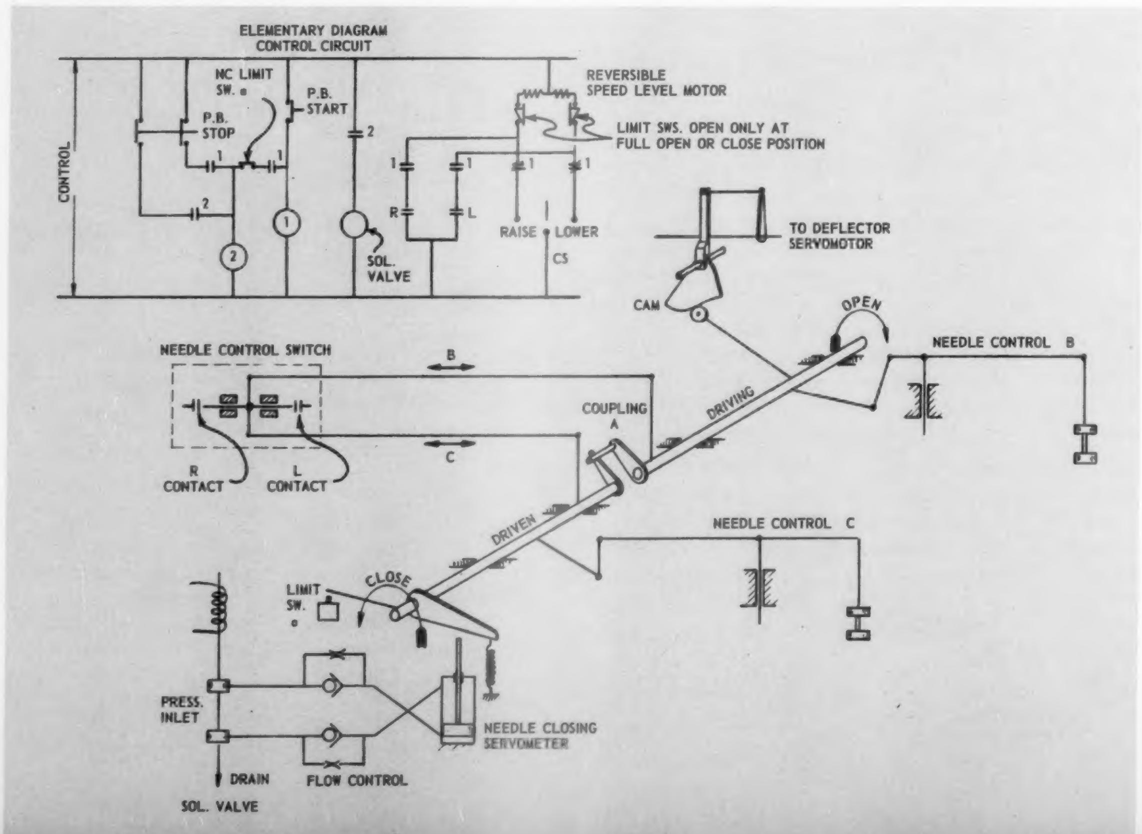
Assuming for the moment that the turbine output versus needle stroke is a linear relationship the turbine output will be the same with four needles closed, and two needles opened three times the amount of movement required to close the four needles from the reference. It is assumed that the reference position is such that three times the movement required to close four needles from the reference does not exceed full open position of the two needles. If the reference is such that the two needles will arrive at full open position before the four needles are closed, the limit switch in speed level raise circuit will open. The power output of the unit will then decrease until the four needles have closed.

When the four needles close, normally closed limit switch *a* will open relay *1* holding circuit, restoring the speed level motor circuits to normal and thus permitting the governor to control two needles in a normal manner. The four needles will remain closed until relay *2* is deenergized by opening momentary stop push button in the holding circuit.

Restoration of all needles to normal control with minimum change in output may be accomplished automatically by additional relays and is no more than a reversal of the operation described.

While the automatic transfer of needles is often called for in specifications for impulse type hydraulic turbines to gain efficiency at lower loads, it is not generally justified because of the cost and complexity of the additional equipment required. However where it is necessary to operate at part loads for long periods and where the stored water is valuable, the gain in efficiency may more than pay for the additional cost. ◆

NUMBER OF JETS in operation is controlled with push buttons. Completely automatic control can be had by replacing push buttons with automatic relaying. (**FIGURE 3**)



SETTING SUB-SOLE PLATES

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Proper setting of sub-sole plates simplifies installation and alignment of heavy machinery. Here is the procedure.

ACCURATE SETTING of sub-sole plates is the first step in the proper installation of heavy machinery. Such equipment as turbine-generator units, kilns, motor-generator sets, ball or rod mills and large pumps and compressors use sub-sole plates as the points of contact between the foundation and the bedplates. Considerable care is required to insure that these plates are set in a level plane; that there is a firm bond between the foundation, grout, and the plate; and that the plates are positioned according to drawing specifications for spacing and elevation.

Prior to the setting of the sub-sole plates, the foundation is prepared and oakum or rags are packed around all foundation bolts to keep chips and grout out of the sleeves. The surface of the foundation is chipped or bush-hammered to provide a rough surface to which the grout will adhere. Since concrete is a porous substance, the grout can be squeezed into minute pores which provide the "hooks" or adherent quality that must be present to insure a tight bond between the grout and foundation.

After the foundation has been bush-hammered, it is wet down with water for approximately two days prior to the actual grouting of the sub-sole plates. One or more bench marks are also placed on the foundation to set up a reference plane. The bench marks are placed 1/8 in. below the reference plane and near the axial centerline of the unit so as not to interfere with the layout positions of the sub-sole plates.

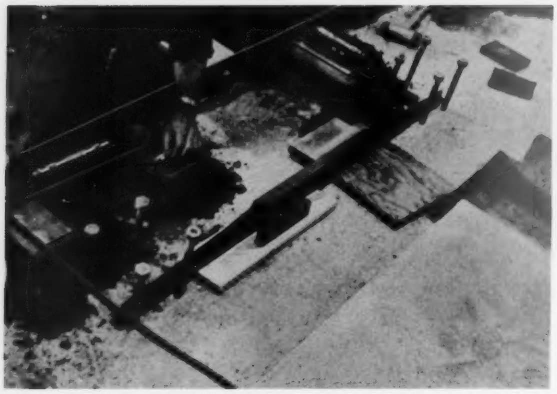
The sub-sole plates, as shipped to the jobsite, will usually have a protective coating which can be removed with a suitable solvent. If in shipping, any burrs or scratches are incurred on the polished side of the plate, these are filed off to provide a perfectly uniform surface.

Grout prepared for sub-sole plates

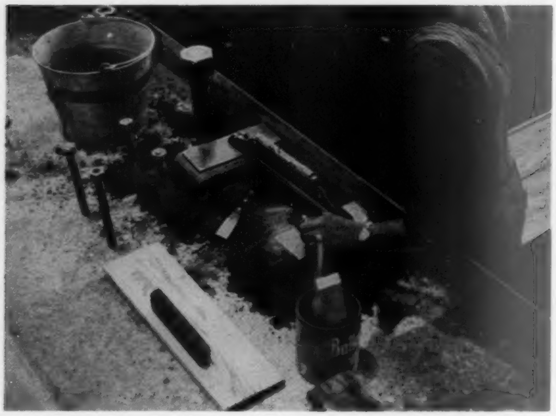
In preparation of the grout itself, the major points to be remembered are the ratio of "sharp" sand to cement and the consistency of the grouting mixture. The accepted ratio is two parts sand to one part cement. Correct consistency is achieved when the grout can be squeezed into a ball by hand with no excess water escaping, and yet can be broken into two pieces without crumbling. Since the bush-hammered foundation is thoroughly wet down prior to the application of this dry grout, the water will draw the grouting mixture into the pores of the concrete foundation, thus providing the required bond. The grout is mixed in small quantities so that it does not "set up" before it is used.

Having insured that the foundation has been properly prepared and cleaned, free of dust, chips, and other foreign material, and that there is a proper mixture of grout, the actual setting of the sub-sole plates is undertaken.

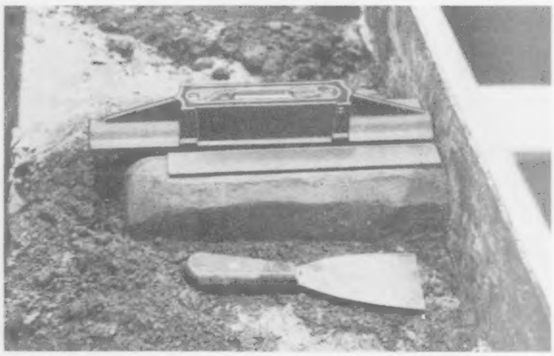
SUB-SOLE PLATE is placed on mound of carefully prepared grout and gently tapped down to the approximate required level. **(FIGURE 1)**



MACHINISTS LEVELS, five foot straight edge and parallel blocks are tools required to properly position the sub-sole plates. **(FIGURE 2)**



PLATES are set with relation to the elevation of other sub-sole plates or with relation to bench marks on the foundation. **(FIGURE 3)**



GROUT is trimmed to symmetrical shape and allowed to set for two hours. Sub-sole plates are then rechecked for correct level. **(FIGURE 4)**

A mound of grout is dumped into the space allotted for the sub-sole with the top of the mound about two inches above the required elevation. The sub-sole plate is placed, polished side up, on top of the mound of grout, and a rubber, wooden, or plastic hammer is used, as shown in Figure 1, to tap down the sub-sole plate evenly to approximately the required elevation.

Plate leveling requires accurate instruments

The pieces of equipment used for leveling the plate are 6 and 12 inch machinists levels, a five foot straight edge, and a set of parallel blocks. These tools are shown in Figure 2.

The levels are used to determine on which side the plate should be tapped to bring it into the horizontal reference plane. Using a firm pressure on the sub-sole plate to prevent rocking, it is alternately tapped with the hammer and checked with the level until it is within the specified level tolerance of 0.0025 in. per foot.

A combination of the 12 in. level, five foot straight edge, and parallel blocks is used, as shown in Figure 3, to determine the relative elevations between sets of sub-sole plates or between sub-sole plates and the bench marks. The elevation of individual plates are adjusted so that no plate is above the reference plane but may be a maximum of $\frac{1}{16}$ inch lower.

The mound of grout is trimmed to a symmetrical shape, usually a right angle parallelopiped, with the top edge of the grout coming to ½ inch below the polished upper surface of the sub-sole plate, as shown in Figure 4.

The grout is allowed to set from one to two hours and then again checked to see that the sub-sole plates are within the allowable elevation and level tolerance; if not, minor corrections are made at that time. Having rechecked all the sub-sole plates, they are coated with a viscous oil making sure that no oil is introduced to the grout. The grout mounds are then individually wrapped with wet burlap and allowed to cure overnight.

After curing overnight, the burlap is removed, the oil is wiped off the plate surfaces, and the sub-sole plates are checked to be sure that they are still level and solidly bonded to the grout.

Elevations set up

After a week of curing and again having rechecked all plates for level, the precision sight level is used to set up the actual elevations. In preparation for this operation, reference is made to the bedplate drawing to pick out suitable stations from which the "shooting" of the sub-sole plates can be accomplished. Care is used in picking these stations since there should be at least one shot of each sub-sole taken from two different stations. To insure greater accuracy, a shot of each plate should be made from a third station. Also, a check is made to determine whether or not the scales used will be high enough for all readings. If the scales are not high enough, parallel blocks are used to elevate the scale.

When using the precision sight level, the following methods are used:

(a) The level is set up, as shown in Figure 5, according to the manufacturer's instructions.

(b) The standard length scales used are the 20 in. and the 40 in. scales. When readings are taken on both scales, a check is made to see if both read the same at 19.5 in. to 20 in. If not, a correction is made to the readings of one scale.

(c) Only one bench mark is used as a base for all differences in elevations.

(d) A series of shots is taken from one station, as shown in Figure 6, and recorded on a standard data form. Another series of shots of the same sub-sole plates are taken from a different station and recorded. The difference in elevations recorded from each station is a check on the accuracy of the readings. The readings are averaged by weighting according to the distance from the sub-sole plates to the stations.

(e) The differences in elevation of each sub-sole plate from the one bench mark is calculated. After determining the high plate, the amount of shim material to be added to each sub-sole plate to insure a level reference plane is calculated and shim packs are prepared for each sub-sole plate. Additional shims are added to the pack to compensate for the elevation deflection of the rotating element or other considerations when required.

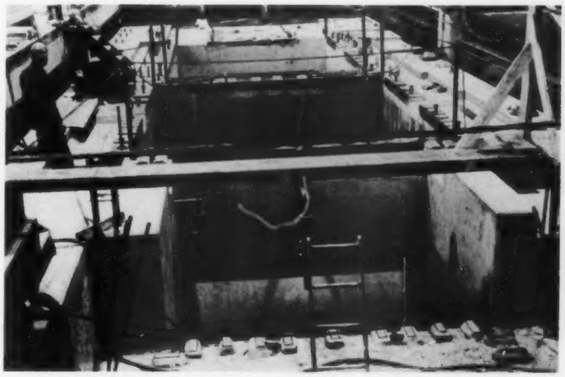
The shim packs are made up from standard thickness shim material cut to the size of the various sub-sole plates. Each shim which is cut is checked by means of a micrometer and the thickness is recorded on the shim with a marking pencil.

After the required shim packs have been made up, they are placed on their corresponding sub-sole plates and the bedplates are placed on top of them as in Figure 7. A check is made to insure that the shim packs are not loose, since such a condition would tend to show that an error was made somewhere in the readings or in the calculations. With all the shim packs tight, the bedplates and anchor bolts are tightened.

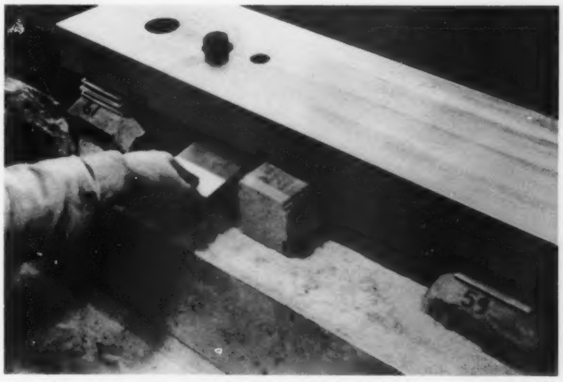
A check is made on the elevations of the bedplate with the precision sight level at the corners and center edges of each bedplate. These readings are taken from at least two different stations to provide a check for accuracy.

Having insured a high degree of accuracy in setting the sub-sole plates and having added the correct amount of shim material, the bedplates will be within the specified tolerance limits of the drawings and installation of the machines can proceed smoothly. ◆

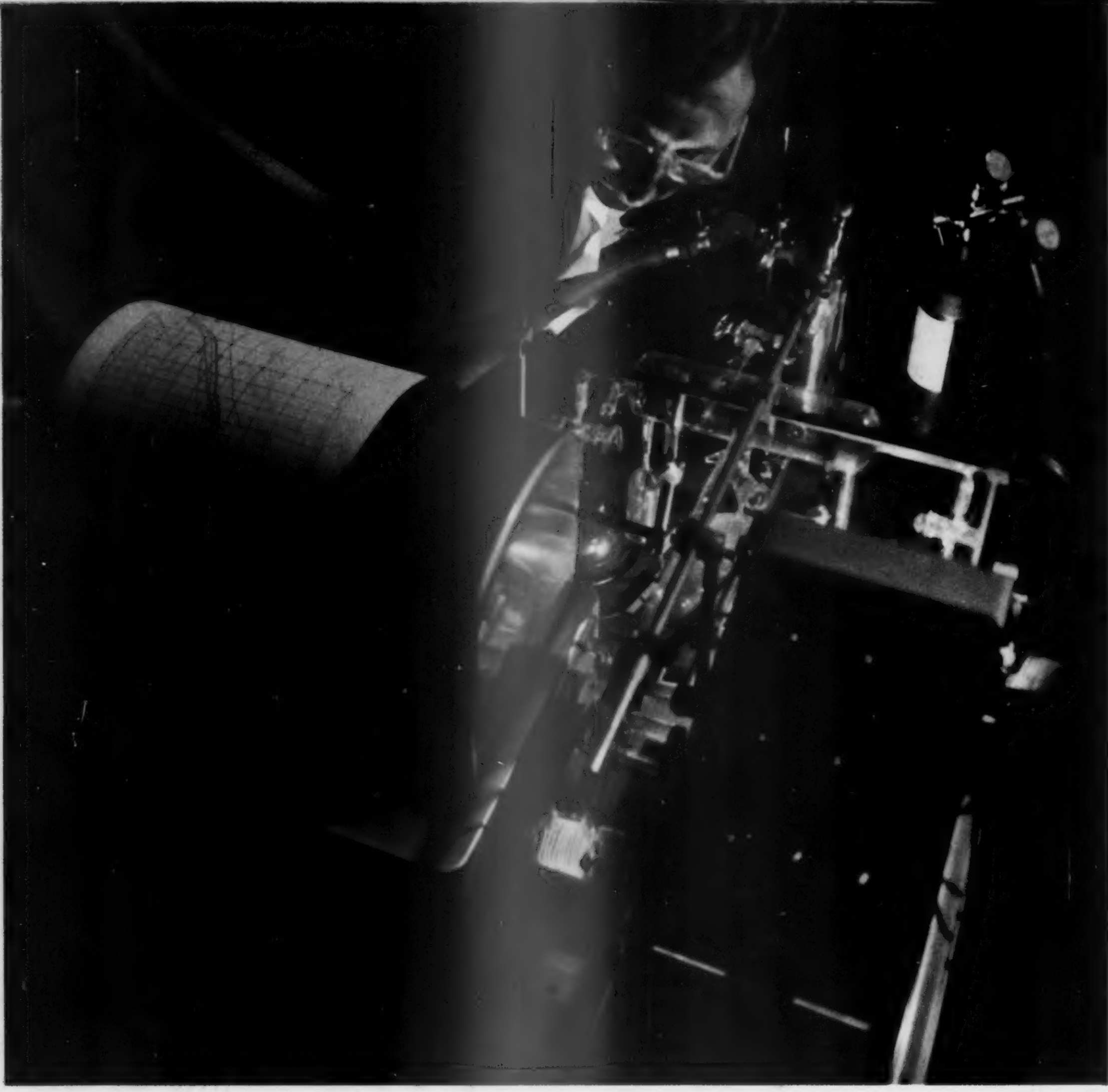
PRECISION SIGHT LEVEL is set up according to manufacturers instructions to find differences in elevation of plates. **(FIGURE 5)**



SERIES OF SHOTS are taken from one station and recorded. Elevations are compared for accuracy with data from another station. **(FIGURE 6)**



SHIMS are placed under bedplate to compensate for differences in sub-sole plate elevation and deflection of rotating elements. **(FIGURE 7)**



Studies With Infrared Radiation

INFRARED RADIATION has proved a versatile tool in exploring many areas of man's curiosity. It is used by scientists to measure the temperature of rocket exhausts, identify precious gems, determine the gases which exist in the atmospheres of other planets, investigate the way atoms are arranged in a molecule, examine the nature of the moon's surface and make photographs in the dark.

Recently, infrared techniques have been applied to investigate the nature of forces holding a thin layer of gas on a solid surface. The surface of glass, brick, metal, or any solid material will remain coated with a layer of gas even after being thoroughly cleaned. Although the layer of adsorbed gas may be less than a ten millionth of an inch thick, its presence may be extremely significant. While processes of lubrication, adhesion, flotation of ores, fracture of materials, and catalysis are all thought to depend on effects of this thin adsorbed layer, details of its influence still remain a mystery.

It is known, for example, that adsorption plays a key role in catalysis, through which the course of chemical reactions can be controlled. The technology of catalysis, basic to a wide variety of commercial operations, has been developed largely as an art rather than a science, and many fundamental questions about this process have not been answered.

As a specific example of the role of catalysis, we may consider the operation of fuel cells, a subject of considerable current interest. Here, catalysis is vital. The ultimate utility of this power source may be determined largely by the success we have in solving catalysis problems.

The infrared apparatus provides basic information about gas adsorption on solids. A more complete understanding of this phenomenon gained through infrared studies can be expected to suggest new process improvements and possibilities.

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